THE ANNUAL CYCLE OF PLANKTON OFF KAIKOURA

A thesis presented for the
degree of DOCTOR OF PHILOSOPHY in ZOOLOGY
in the University of Canterbury,
Christchurch, New Zealand.

by

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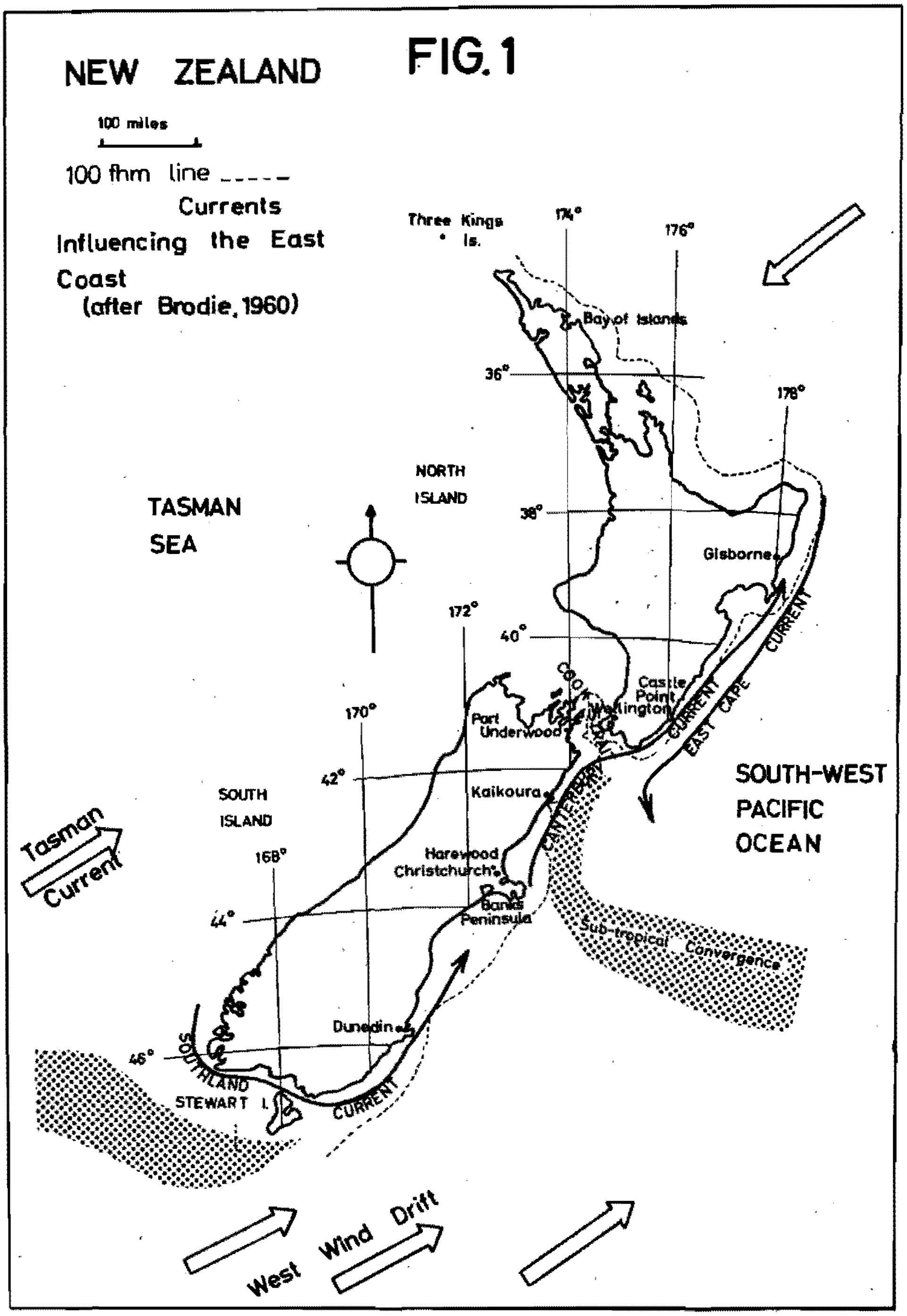


NEW ZEALAND
FIG. 1
100 miles
100 fhm line
Currents Influencing the East Coast
(after Brodie, 1960)
Three Kings Is.
174°
176°
178°
Bay of Islands
36°
38°
40°
42°
44°
46°
172°
170°
168°
NORTH ISLAND
SOUTH ISLAND
TASMAN SEA
Gisborne
Castle Point
Wellington
COOK STRAIT
Port Underwood
Kaikoura
Harewood
Christchurch
Banks Peninsula
Dunedin
STEWART I.
SOUTHLAND CURRENT
CANTERBURY CURRENT
EAST CAPE CURRENT
SOUTH-WEST PACIFIC OCEAN
Sub-tropical Convergence
Tasman Current
West Wind Drift

A. INTRODUCTION

It is known that the Kaikoura region is influenced by several interesting hydrological phenomena. These include the upwelling of cold water in summer over the Conway Trough (Garner, 1961) and the appearance of warm water at the same place in winter (Houtman, 1965).

It is to be expected from such situations that nutrient enrichment of surface waters would occur and that the growth and production of the plankton populations would be correspondingly enhanced. This expectation is substantiated by the fact that the Kaikoura region is the breeding and/or feeding grounds for large numbers of sea birds, seals, fish and other marine mammals (Stonehouse, 1965).

The purpose of this study was to describe an annual cycle of zooplankton quantitatively and a phytoplankton cycle by the chlorophyll a content. By making comparisons with other regions it was hoped that the effect of the known hydrological phenomena, occurring at Kaikoura, on the quantity of plankton present would be defined, as well as any obvious discrepancies in the chemical composition of the zooplankton. In parallel with the above work, some hydrological factors involved with the plankton were defined and the relationships of selected species to the hydrological situation were investigated.

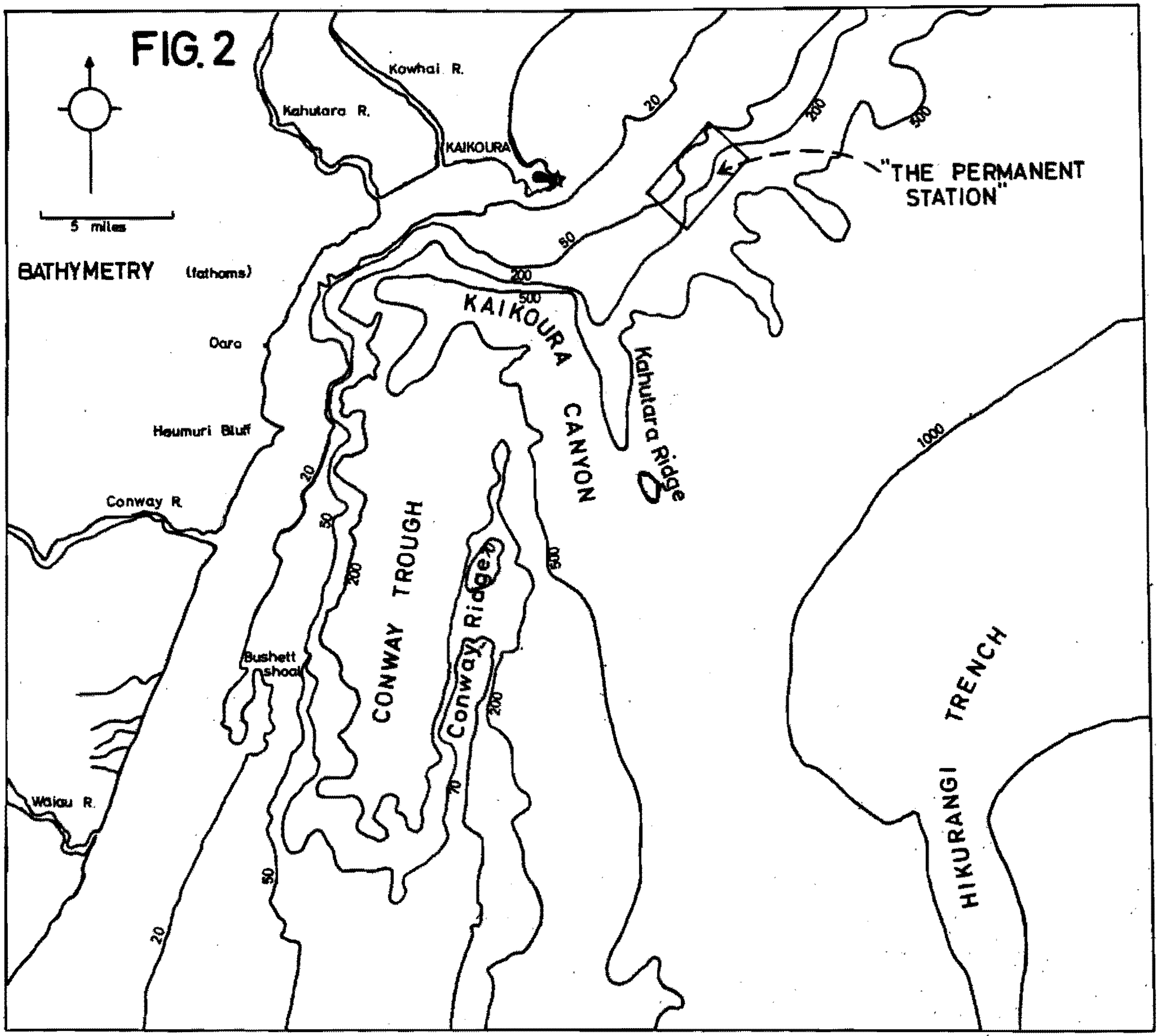
Previous Work Relevant to the Kaikoura Region

Hydrology

The Kaikoura region is influenced by two coastal currents, one of subantarctic and the other of subtropical origin.

Canterbury current This is formed from the West Wind Drift by the northward movement of subantarctic water from Banks Peninsula extending occasionally as far as Gisborne (Brodie, 1960; Garner, 1961).

FIG. 2



5 miles
BATHYMETRY (fathoms)
Kowhai R.
Kahutara R.
KAIKOURA
"THE PERMANENT STATION"
Oaro
Haumuri Bluff
Conway R.
Bushett shoal
Waiau R.
KAIKOURA CANYON
Kahutara Ridge
CONWAY TROUGH
Conway Ridge
HIKURANGI TRENCH
20
50
200
500
1000
70

<u>East Cape current</u> This bounds the Canterbury Current on the east and is a south-flowing tongue of subtropical water (Fleming, 1952; Garner, 1953; 1954; 1961; Brodie, 1960). The influence of this current varies considerably from year to year. For example, Garner (1954) showed that the East Cape Current extended the length of the country in 1951, while its influence did not go much past Cook Strait the following summer.

The form of the boundary between subantarctic and subtropical water masses in the south-west Pacific has been given by Deacon (1937); but what is more relevant to this study is the characterisation of the boundary in New Zealand waters where it is the confluence of the two above mentioned currents in the coastal region. The relationship of the Subtropical Convergence (the above boundary) to New Zealand has been considered by Fleming (1952) and Garner (1954), and summarised by Garner (1959). Garner (1959) defines the Subtropical Convergence as following "approximately the isotherms of 15°C in February and 10°C in August and the isohalines of 34·7 to 34·8°/oo with little seasonal variation" (Fig. 1). However, it is noted by Garner (1954) that, because of the fluctuations in the East Cape Current, seasonal and yearly fluctuations in the position of the Convergence are to be expected.

Garner (1961) described invasions of subtropical water off the Kaikoura coast at two-monthly intervals in 1955 and noted two occasions when the invasions were particularly strong. These seemed to be connected with pulses of cold water appearing in southern Cook Strait as upwelling subantarctic water. He also noticed that cold water upwelled over the Conway Trough in summer, while Houtman (1965) found that warm water rose to the surface in the same place in winter. The bottom configuration itself (Fig. 2) is probably one of the factors, in conjunction with the current and wind systems off the east coast of New Zealand, making

Fig. 2·5: Mr R. Baxter's VIRGO

possible the occurrence of these phenomena.

Plankton

Many species of zooplankton found in the New Zealand region have been recorded by expeditions to these shores. The most important of these was the "TERRA NOVA" which carried out investigations in New Zealand waters during the winter of 1911; a large number of stations were kept in the vicinity of Three Kings Island. Other expeditions which gathered information relevant to the New Zealand region were the "CHALLENGER" in 1873-76 and the "DANA" in 1928-29, although few plankton reports have been published from the latter expedition.

No attempt, until recently, has been made to collect seasonal plankton data. Crawford (1949), Brewin (1952) and Cassie (1960) described a phytoplankton season in Cook Strait; Otago Harbour; and Hauraki Gulf, Wellington Harbour and Cook Strait respectively. Wear (1965) studied an annual cycle of zooplankton in Wellington Harbour, but this is the first quantitative seasonal study to be carried out in open waters.

Before the work of Bary (1951) there was little attempt to relate the zooplankton distribution to the prevailing hydrological conditions in New Zealand waters. Garstang (1933) in his discussion of the Doliolids appears to have been the only author of a "TERRA NOVA" report to recognise that upwelling south of Three Kings Island might have been necessary to explain the facts of distribution.

General Methods and Apparatus

As it was intended that the phytoplankton, zooplankton and the sea water itself be studied it was necessary, in order to be able to handle the data collected, to confine the sampling to one area. For this reason the "Permanent Station" (Fig. 2) was chosen about five miles east of the

Fig. 3: The arrangement of meter wheel and snatch block

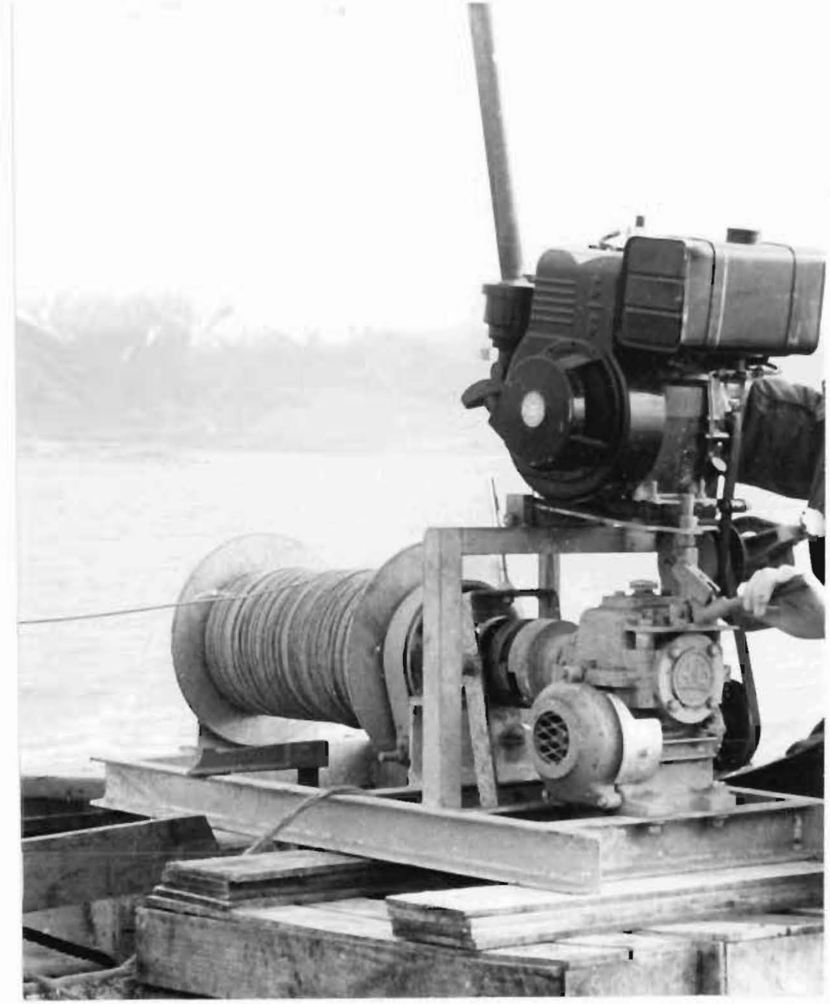


Fig. 4: The winch used during the course of this study

Kaikoura Peninsula at a depth of approximately 200m. Conclusions will therefore be confined to this "Permanent Station".

For the purposes of this study three pieces of equipment were specially constructed in the workshop of the Zoology Department. They are:

Portable Winch This winch was capable of lifting one ton at variable speeds and carried 600 metres of 4mm diameter galvanised wire rope (Fig. 4).

Five Litre Water Sampler A modified Van Dorn water sampler, similar to the one used by Davis (1957), was constructed (Fig. 6).

Zooplankton Sample Divider This Sample Divider was made to the specifications of Kott (1953), (Fig. 7).

Sampling Procedure

The information obtained during this study was collected from Mr R. Baxter's "VIRGO", a 38 ft fishing boat (Fig. 2·5). Sampling was begun between 8.30 and 10a.m. on one day every fortnight and the records were taken in exactly the same order. The order in which the samples and recordings were taken is as follows:

1) The winch, meter wheel and second snatch block were set up as in Figs 3 and 4, and the 55lb lead weight attached to the end of the wire rope.
2) The Clarke-Bumpus sampler (Fig. 5) was then attached to the wire about two metres above the weight. An oblique haul was then taken from about 200 metres with the boat travelling at approximately two knots. The wire rope was wound in at a speed such that the haul lasted 10 minutes in summer and 15 minutes in winter. Then four horizontal hauls were made with 5m, 22m, 100m and 180m of wire out respectively. Two messengers were used to open and close the sampler as required. Thus horizontal hauls were not contaminated by animals above the sampling depth. The

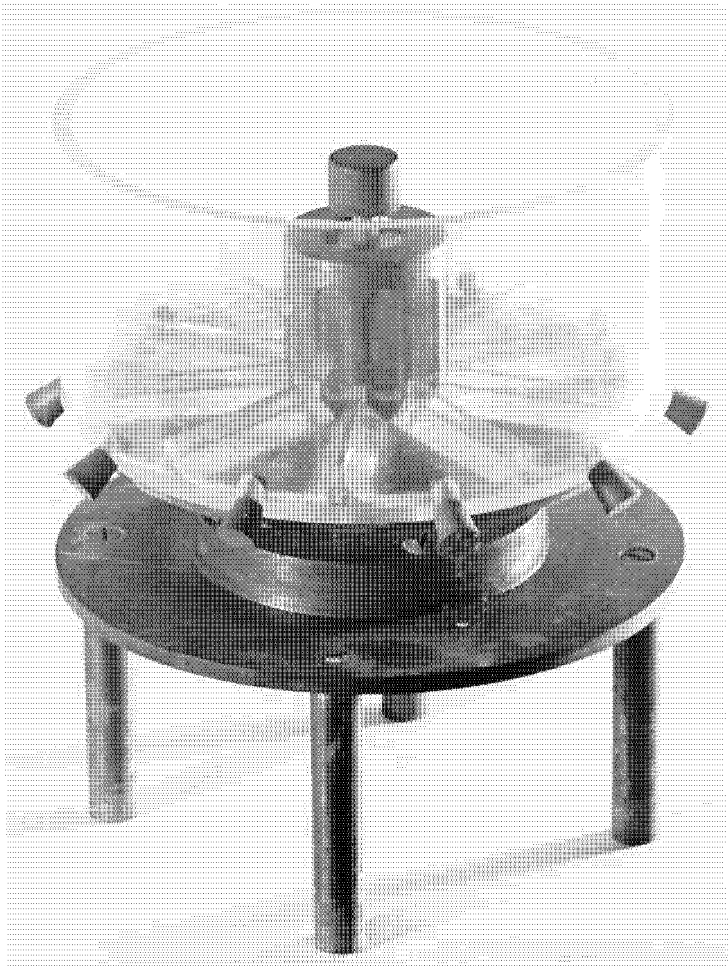


Fig. 7: Plankton Sample Divider

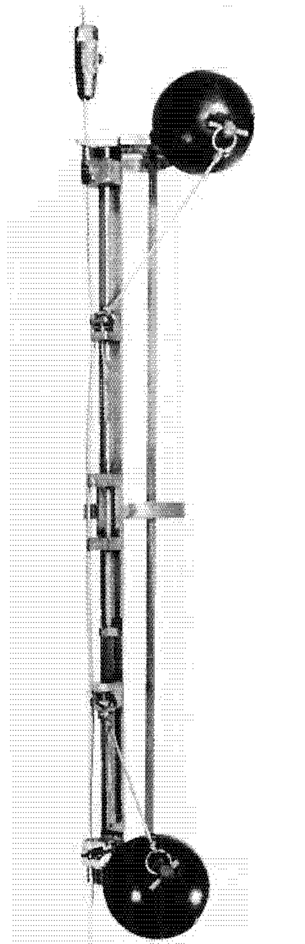


Fig. 6: Van Dorn Water Bottle

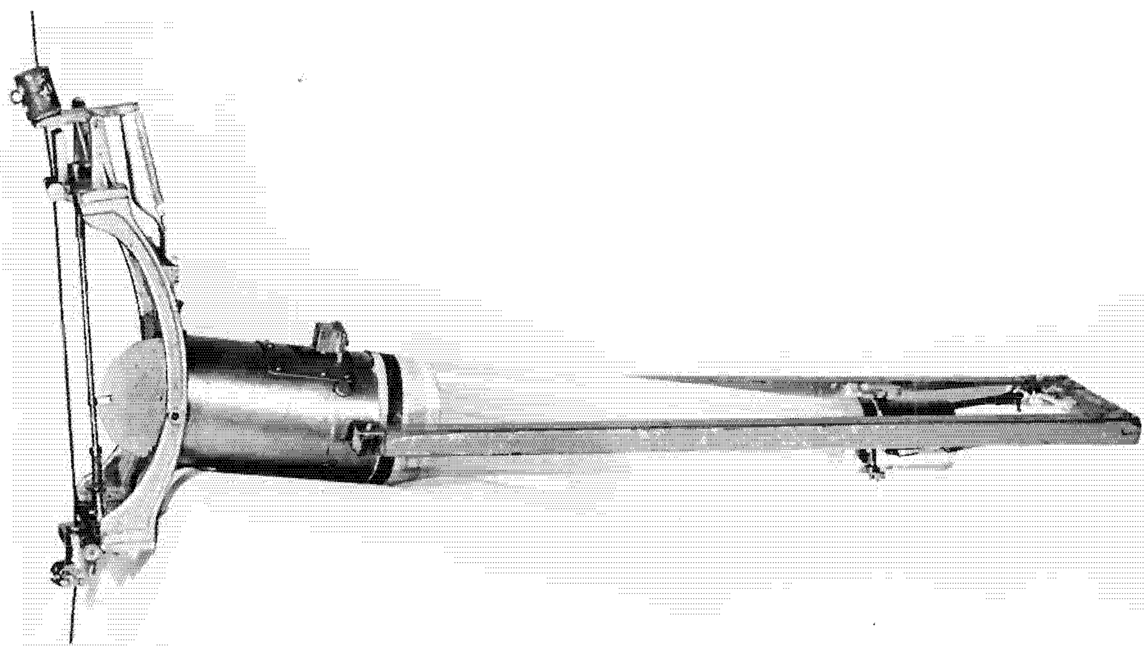


Fig. 5: Clarke-Bumpus Plankton Sampler

maximum sampling depth was measured by attaching a Kelvin Tube, in its holder, to the wire just below the Clarke-Bumpus sampler. As each zooplankton collection was brought to the surface, the net was washed from the outside with sea water, and the contents of the bucket washed into a preserving jar containing enough formalin to make the resulting solution 5% formalin in sea water. A small net, 200 meshes to the inch and aperture size 61 microns, was trailed from the Clarke-Bumpus frame during the horizontal hauls. The phytoplankton and zooplankton samples thus captured were preserved as above.

3) Next, the Van Dorn water sampler was attached to the wire rope in the open position. With this piece of apparatus five-litre water samples were taken at 0, 10, 25, 50, 75, 125 and 200 metres' depth by sending down a messenger when the sampler had reached the required depth. Each five-litre water sample was stored in a polythene bottle for transport to the laboratory where it was processed not more than eight hours after collection. The greatest portion of sea water was used for the extraction of plant pigments from the phytoplankton contained in it, but 300ml and 150ml were taken out for salinity and nitrate determinations respectively.
4) Then the bathythermograph was lowered to 140m and raised while the surface temperature was being recorded by thermometer.
5) A vertical zooplankton haul was then taken with an N70 net and the sample preserved as in 2).
6) The final recording was a Secchi disc reading.

B. DEFINITION OF THE ENVIRONMENT

Methods

a) Salinity

On each sampling day approximately 300ml. of sea water were obtained from 0, 10, 25, 50, 75, 125 and 200 metres' depth (see page 5) and stored in medicine bottles. These bottles were then stoppered with waxed corks and sealed with more wax. At a later date the salinity was determined by the Knudsen method as detailed by Oxner (1920). The room in which the titration was carried out was kept at approximately 20°C by a thermostatically controlled heater.

Modifications to the method included the use of a magnetic stirrer and an indicator diluent solution as described by Strickland and Parsons (1960). A certain amount of Copenhagen "Eau de Mer Normale" was obtained as the standard, but as it was necessary to conserve it a substandard reference solution, chlorinity 19·15‰, was collected. As Knudsen's tables require a substandard with chlorinity within 19·31 - 19·45‰ his "Table of Titration" could not be used. Instead, the method of McGary (1954) was employed, as it may be used with a reference solution of natural sea water of any chlorinity.

Two burettes were used, with a Knudsen pipette, in the course of the work; the first was not automatically zeroing and was graduated in 0·02ml. for the last 10ml. with a bulb above the graduations; the second was a Knudsen burette. The last seven days' determinations were done with the latter burette. Before the change-over the two burettes were compared. Ten identical samples of sea water were measured out with the Knudsen pipette. Five were then titrated by the first burette and five by the Knudsen burette, after titration against Copenhagen "Eau de Mer Normale". The results are shown over leaf in Table 1.

Table 1. Comparison of the first burette with the Knudsen burette

	Mean of 5 Titrations S^{o}/oo	S.D.
First burette	34·42	0·0065
Knudsen burette	34·42	0·0064

Although a high degree of precision was attained in a short space of time with one burette this was not sustained over longer periods. The true values for the salinities lie within a range greater than $\pm0·033$ but less than $\pm0·085$ from the quoted figures (Appendix II); these two values are derived from the precision limits given by Strickland and Parsons for the determination of salinity by titration. It was concluded that the change in burettes did not affect the consistency of results.

b) Temperature

On each sampling day the surface temperature was recorded with a Centigrade thermometer with 1·0°C graduations. In addition, the subsurface temperature was recorded with a 450 ft bathythermograph. The temperatures were read to the nearest 0·1°C.

c) Density

The density (σt) was calculated from the tables of Matthews (1932) at depths of 0, 10, 25, 50, 75 and 125 metres. In considering the values of σt, two facts must be taken into consideration. (i) The decimal places in the temperature records are only estimates.

(ii) The salinity and temperature observations were not taken simultaneously.

d) Nitrate

On each sampling day about 150ml. of sea water were taken from 0, 25, 50, 75, 125 and 200 metres' depth (see page 5) and processed not more than eight hours after collection. The method used for the determination of nitrite-nitrate nitrogen was that of Mullin and Riley as modified by Strickland and Parsons (1960). Calibration of the method was carried out on each batch of seven samples using a 30 µg at/L standard nitrate solution. The extinction of the pink dye formed was measured with a "Spectronic 20" colorimeter-spectrophotometer. Nitrite-nitrate nitrogen is hereafter referred to as nitrate.

The results for the first five days' sampling (14 April to 15 July 1964 inclusive) are not reliable since contaminated acetone was used. Correction factors were estimated for those five days in the hope that the figures would help complete the cycle.

Results

SALINITY AND TEMPERATURE

In the Temperature and Salinity Depth Profiles (Figs 14 and 15) three facts are immediately obvious:

1) There were winter subsurface maxima in both temperature and salinity.
2) The water column was almost isohaline in structure between November '64 and February '65.
3) There were larger fluctuations in subsurface isotherms in late summer than in early summer, but not as large as in winter.

These facts may be further interpreted under the following headings:

a) The Influence of Subtropical and Subantarctic Waters
b) The Influence of Coastal and Oceanic Waters
c) The Relationships of Summer Subsurface Temperature Fluctuations

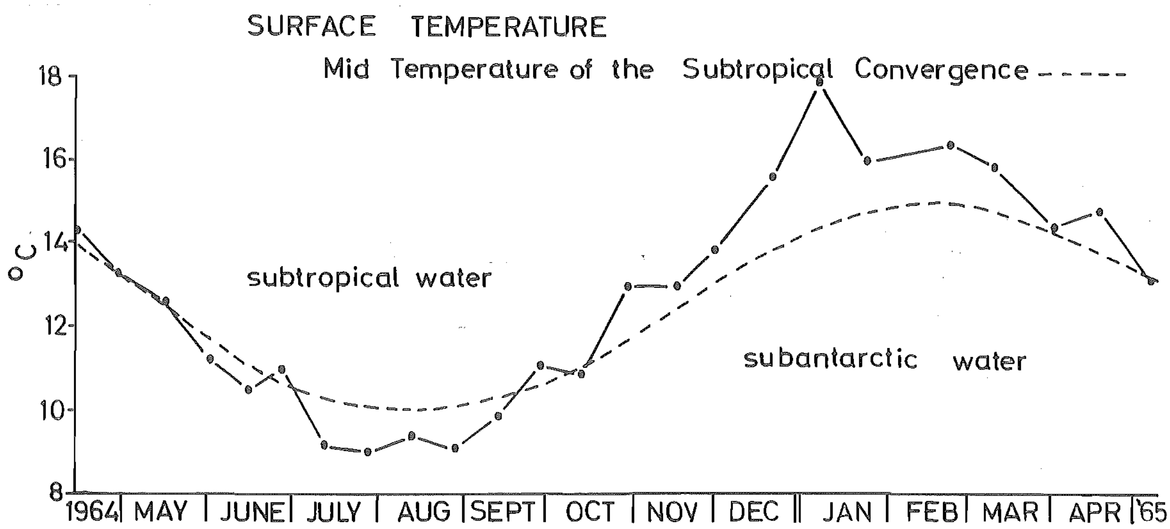


Fig. 8: Surface Temperature at the Kaikoura "Permanent Station"

a) The Influence of Subtropical and Subantarctic Waters

Garner (1959) defined the subtropical convergence as approximately following isotherms 15°C in February, 10°C in August and the isohalines 34·8 and 34·7‰ respectively.

Subtropical water cannot be recognised from the salinities recorded in this study because of dilution by coastal water and mixing with subantarctic water although higher values were recognised despite dilution elsewhere; for example, a salinity of 34·83‰ was recorded in May at 125m and a salinity of 34·87‰ was found during June and September at 50m. It will be assumed that the temperatures above Garner's mid-temperature limits for the Subtropical Convergence are indicative of subtropical influence at the "Permanent Stations". In Fig. 8 Garner's (1959) winter and summer limits for the general midpoint of the Subtropical Convergence have been plotted as the maxima and minima of a sine curve on to the actual surface temperatures. Thus it may be seen in Fig. 8 that from the middle of May 1964 until October 1964, surface temperatures were below those given for subtropical water, except on two occasions: one at the end of June 1964 and the other at the end of September 1964, while surface temperatures were well above the limits between October 1964 and May 1965. Temperatures below the limits for subtropical water probably indicated subantarctic influence.

Taking into account the fact that in winter the water was almost homothermal, it is possible to designate the origin of water in the whole column. Thus, in Fig. 14 between July and mid-September, patches of subtropical water appeared on 2 and 16 August '64 and 13 September '64 at various positions in the water column, although their influence was not recorded in the surface temperatures.

Once temperature stratification had commenced it became more difficult to designate the origin of the water in the vertical plane. Bary (1959a) showed, by constructing a section from Wellington to Dunedin for March 1951, that subtropical water was a layer 35–60m deep lying over subantarctic water. On his diagram the 14·5°C isotherm marked a definite boundary between subantarctic and subtropical waters. This temperature (14·5°C) corresponded with the surface limit for subtropical waters in March (see Fig. 8). Therefore the surface limits for subtropical water, which range between 10°C in August and 15°C in February, will be used here, in the vertical plane, to indicate water of subtropical origin. The varying influence of subtropical and subantarctic waters is summarised in Fig. 14.

The Relationships with Previous Work

Houtman (1965) recorded upwelling warm water in June over the Conway Trough and indicated how it may occur. He recorded water of subtropical origin in two forms:

(i) as a tongue at 200m depth, reaching from the Hikurangi Trench into the Kaikoura Canyon, and

(ii) as "Canyon Water" which originated from the above tongue, was modified by mixing with river discharge and flowed out of the Canyon at the surface, moving over the deepest part in a seaward direction.

In the present study, during winter, as warm water influenced the surface layers on only two occasions, it is very likely that subtropical water in form (i) was recorded at the "Permanent Station". There was probably a particularly strong flow of subtropical water on the two days 26 June and 26 September '64 when high surface temperatures were recorded (Fig. 14).

Garner (1961) in 1955 recorded surface incursions of subtropical water, near the Kaikoura coast, at intervals of approximately two months over the whole year. During the present study, maximum subtropical influence was noted at the end of June, September and October '64; January and

April '65 (Fig. 8). These intervals are not as regularly spaced as those recorded by Garner, possibly because of the fortnightly sampling at Kaikoura.

It was pointed out by Houtman (1964), with evidence from Garner (1961), that subtropical water appears near the Kaikoura Peninsula as temporary intrusions which probably occur frequently, but are of short individual duration, at least, at the surface.

b) <u>The Influence of Coastal and Oceanic Waters</u>

Oceanic and Coastal waters differ fundamentally when the vertical distribution of salinity is considered. Over the continental shelf salinity usually increases with depth, adding to the thermal stability of the water column, while off-shore in deep water it decreases in general with depth to 800m (Fleming, 1948).

It may be seen in Fig. 15 that the character of the water column at the "Permanent Station" was primarily coastal. This situation was modified by surface and subsurface invasions of high salinity (Fig. 15), warm (Fig. 14) waters, and by fluctuations in surface dilution by river waters (Fig. 15). These modifications produced fluctuating oceanic influence into the characteristic coastal waters during autumn, winter and early spring; but in summer (10 November '64 to 24 February '65) the water column was more constantly oceanic, although the salinities observed were not high enough to indicate water of entirely oceanic origin. Two other characteristics placed the summer water as being of oceanic origin. These were:

1) The lack of strong increase in salinity with depth. The greatest difference in salinity between 0m and 200m was $0{\cdot}18^{o}/oo$.
2) The presence of a nearly homohaline top layer which

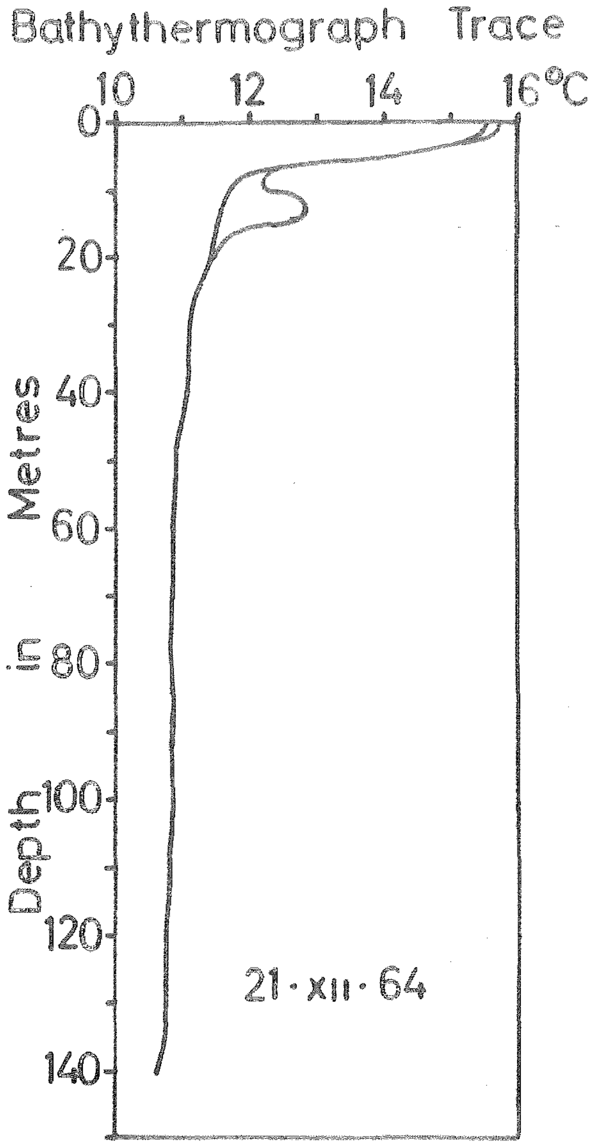


Fig. 9: Bathythermograph Trace taken on 21 December '64 at the Kaikoura "Permanent Station"

Defant (1961) recorded as being characteristic of nearly all stations in subtropical oceans. In addition, the summer salinity maxima observed at the "Permanent Station" appear similar to those noted by Sdubbundhit and Gilmour (1963) in subtropical water off the South East coast of the North Island.

c) <u>The Relationships of Summer Subsurface Temperature Fluctuations</u>

Only the downward plunge of isotherms on 7 January '65 has, so far, been explained as a surface incursion of subtropical water. The other summer isotherm fluctuations will be discussed here.

The downward movement of surface isotherms on 12 March (Fig. 14) is puzzling as there was no surface increase in temperature. On that date it appeared almost as if surface waters had replaced bottom waters. This hypothesis is borne out to some extent by the observed low salinities (Fig. 15) and the plankton present at greater depths which appeared to have surface characteristics, i.e. a large proportion of <u>Oithona sp</u>. and <u>Acartia clausi</u> with only rare occurrences of other copepod species.

The result of upward movement of isotherms was found on 21 December '64, 24 January and 4 April '65 (Fig. 14). Of these, the one on the 21 December is the most note-worthy, as a surface thermocline was formed in which the temperature decreased 4°C in 8 metres (Fig. 9). The double trace recorded in Fig. 9 has been disregarded as it was probably a product of the faulty operation of the bathythermograph.

It does not seem possible that the situation on 21 December was the result of horizontal water movements. While the lower isotherms had been rising towards the surface, the surface temperature itself had shown a marked increase

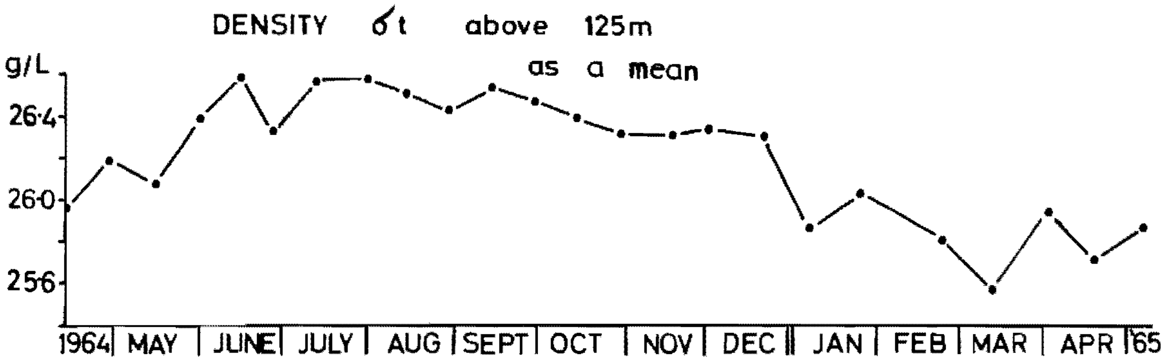


Fig. 10: Mean Density (σt) above 125m at the Kaikoura "Permanent Station"

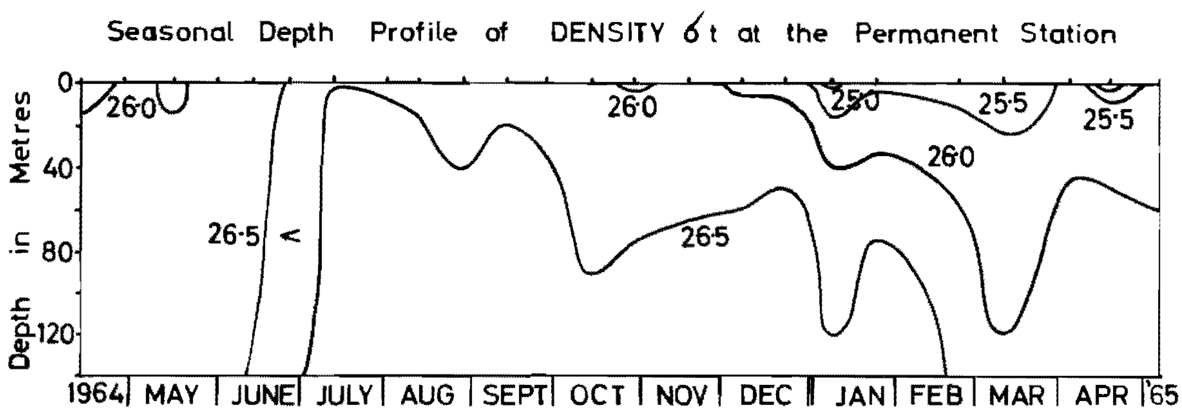


Fig. 11: Seasonal Depth Profile of Density (σt) at the Kaikoura "Permanent Station"

of $4^{\circ}C$ in just over four weeks (Fig. 14). It is possible that an upwelling situation was recorded on this day, similar to that noted by Garner (1961), in summer, south of the Kaikoura Peninsula. This is substantiated by the fact that nitrate enrichment of the surface layers took place on 21 December '64 (Fig. 13). There is no record of cold water reaching the surface over the Conway Trough at the beginning of 1965.

The rises of bottom isotherms, as noted on 24 January and in April '65 could be attributed to upwelling as described above or to the return to an average situation after, on one hand, a strong invasion of subtropical water on 7 January, and on the other, a lowering of surface isotherms on 12 March, discussed previously (Page 12).

DENSITY

The invasions of warm water of high salinity in winter and the fluctuations in surface and subsurface temperatures in summer had a marked effect on the density (σt). The invasions on 16 May and 26 June '64, and downward plunges of isotherms on 7 January and 12 March '65, are shown on Fig. 10 as drops in the mean density (σt).

The seasonal changes in stratification are best shown by the Seasonal Depth Profile of σt (Fig. 11). The water column from 1 June to 12 July was almost homogeneous and remained so until October '64, except for slight stratific- ation because of diluted surface waters (Fig. 15). Mixing had been taking place over that period, June to October, as temperature stratification was not observed until October '64 (Fig. 14). Summer density stratification (Fig. 11) was at its greatest on 7 January '65. This corresponded with the strong surface invasion of subtropical water (Fig. 14).

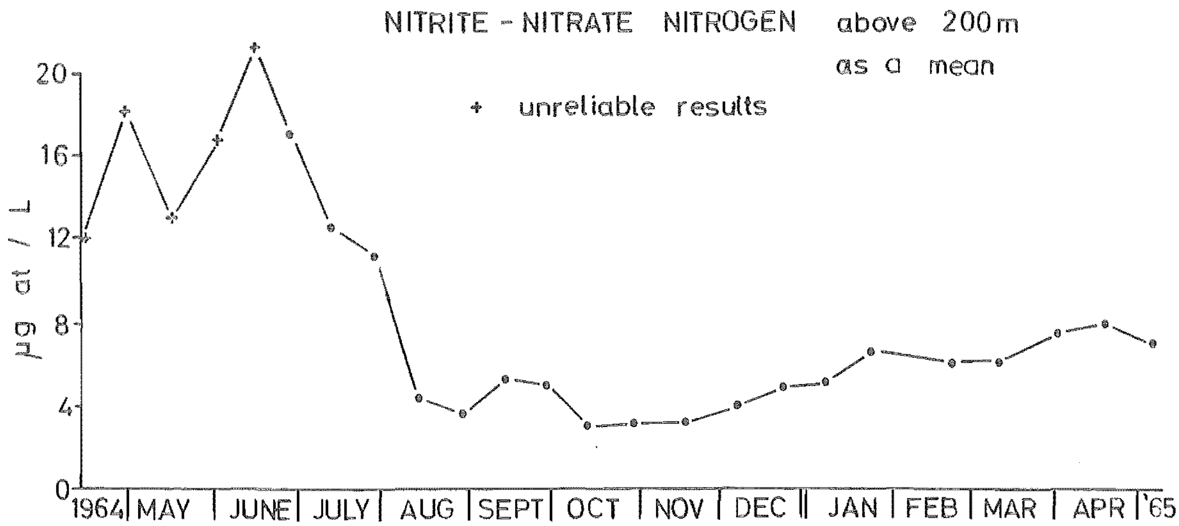


Fig. 12: Mean Concentration above 200m of Nitrite-Nitrate Nitrogen (µg at/L) at the Kaikoura "Permanent Station"

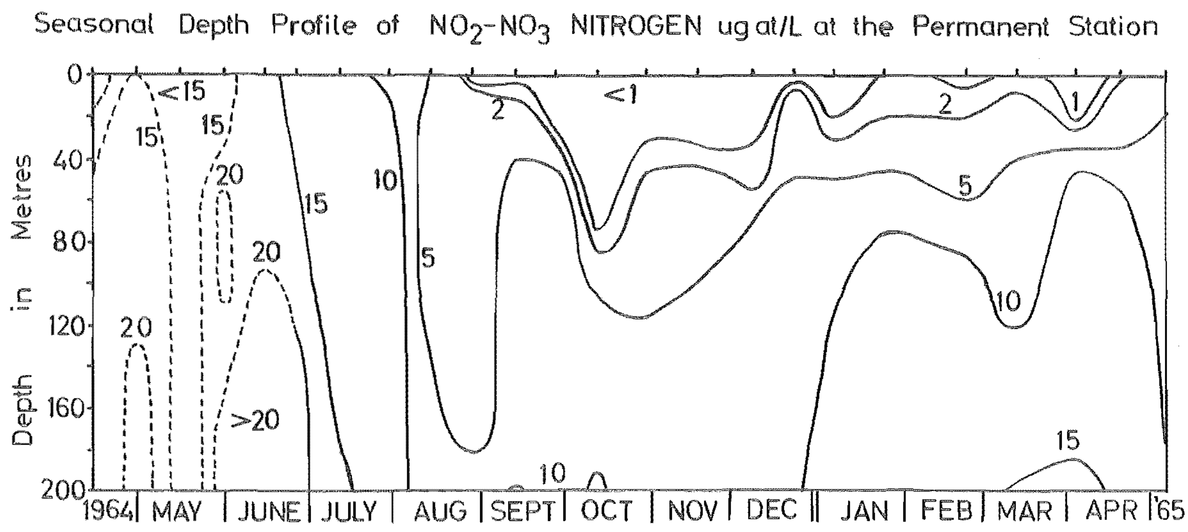


Fig. 13: Seasonal Depth Profile of Nitrite-Nitrate Nitrogen (µg at/L) at the Kaikoura "Permanent Station"

NITRATE

In Fig. 12 it may be seen that the greatest nitrate values were found in winter; the first mean amount reliably detected was 17·0 µg at/L on 26 June '64. From then until 29 August '64 there was a rapid decrease to 3·7 µg at/L. Following this there was a small increase on 13 and 26 September, then a decrease to a minimum of 3·0 µg at/L on 11 October. The mean amount of nitrate rose slowly following the minimum until sampling finished, but the rise was not regular. Peaks were reached on 21 December '64, 24 January and 18 April '65.

The above-mentioned peak concentrations of nitrate (Fig. 12) corresponded with rises in the nitrate contours (Fig. 13) which resulted in increased nitrate concentrations in the upper water layers. This was particularly marked on 13 and 26 September and 21 December '64. The winter was notable for the rich nitrate concentration; at least 26·8 µg at/L was found at 200m on 26 June '64. From spring onwards there was less than 1 µg at/L at the surface, and down to varying depths - a maximum of 75m. This meant that the nitrate was almost exhausted in the surface layers.

Comparisons with Other Areas

Two areas have been chosen for the purpose of comparison.

a) New York Continental Shelf

A position, over the continental slope off New York (Ketchum, Vaccaro and Corwin, 1958), similar to the position of the "Permanent Station", was chosen. Their series of stations were at approximately the same latitude in the northern hemisphere as Kaikoura is in the southern hemisphere.

Ketchum et al found similar nitrite-nitrate nitrogen values for the five months they sampled, except in the winter months. Concentrations of 20 µg at/L were never found much

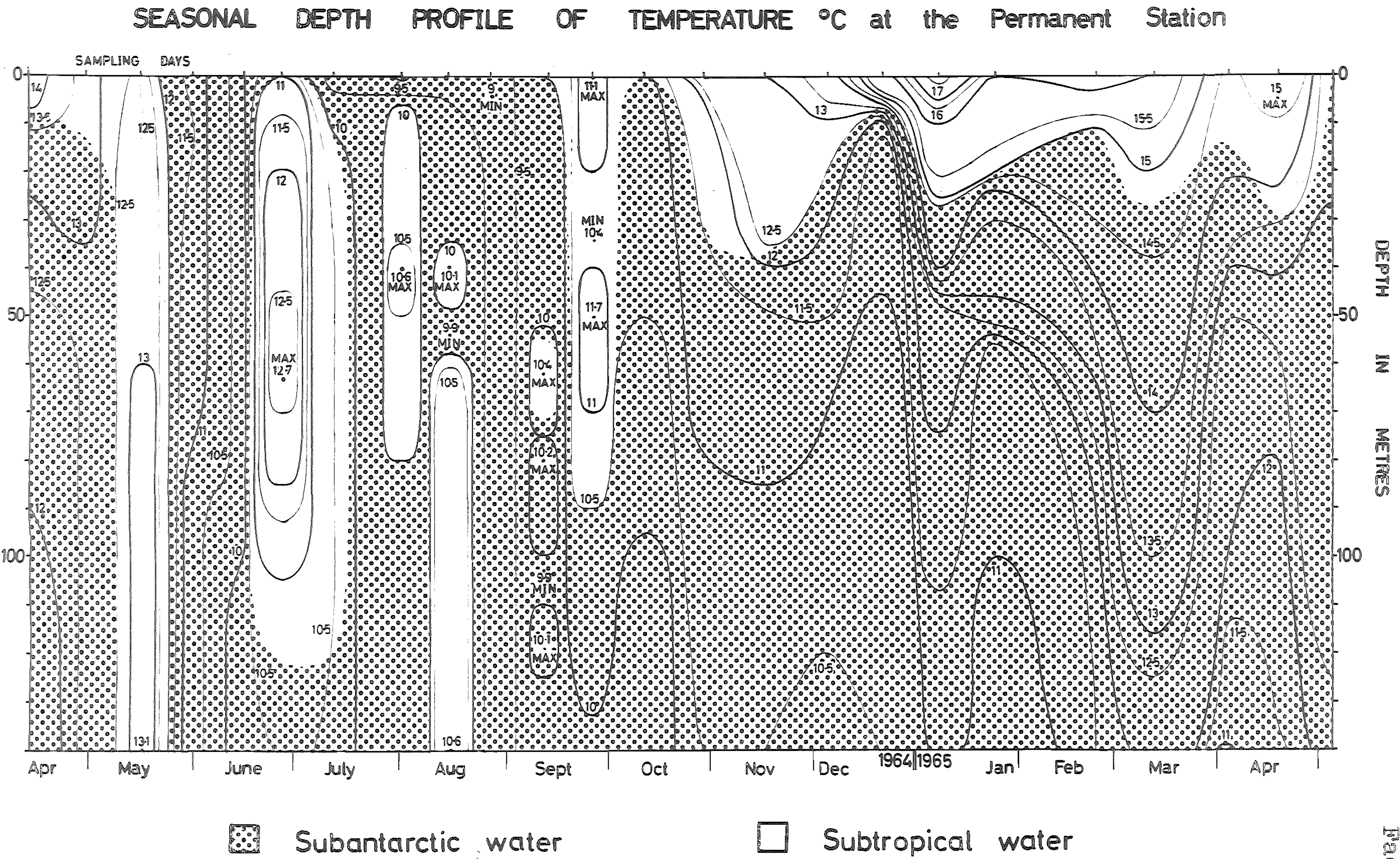


Fig. 14: Seasonal Depth Profile of Temperature at the "Permanent Station"

above 200m off New York, whereas such a value was found at least as high as 120m at Kaikoura. Winter surface values off New York were never greater than 7 µg at/L compared with 13 µg at/L found in June at Kaikoura.

b) Sydney Continental Shelf

The second area chosen was Humphrey's (1960) 100m station off Sydney, 8° farther north than Kaikoura.

Humphrey reported levels of nitrate nitrogen comparable with those found at Kaikoura, except winter surface values were not high. The amount of nitrate at the surface was less than 1 µg at/L all year round off Sydney. Humphrey's values exclude nitrite nitrogen, but as the nitrite nitrogen is rarely greater than 10% of nitrite plus nitrate nitrogen, his results may still be compared with the Kaikoura ones. The facts that the Sydney Station was 8° farther north than Kaikoura, that the temperature structure never broke down completely in winter, and that Sydney coastal waters are entirely under subtropical influence, account for the above differences.

In neither of the areas compared with Kaikoura did the 2 µg at/L contour appear above 30m in summer, whereas this was so on 21 December '64, 24 January, 24 February and 12 March '65 at Kaikoura.

DISCUSSION

At Kaikoura there was a higher winter maximum concentration of nitrate compared with the coastal waters off either New York or Sydney. This fact must be connected with the subsurface warm water intrusions and the mixing that must have resulted, especially during June when the water column had almost homogeneous density. There appears to have been renewal of surface nutrients (as shown by the nitrate) in

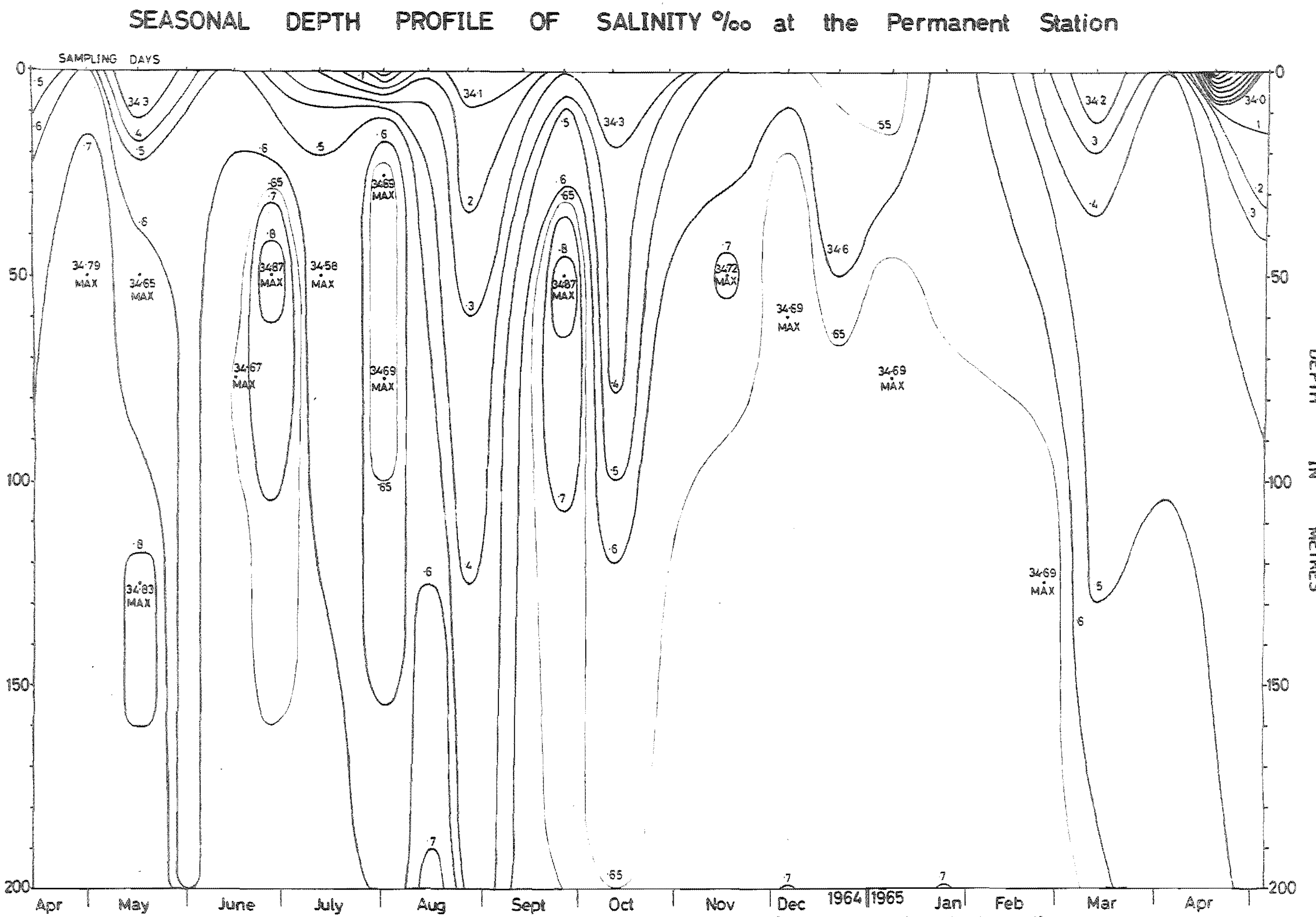


Fig. 15: Seasonal Depth Profile of Salinity at the "Permanent Station"

Face 16

September, December, January and perhaps April (Fig. 13). This may have been associated with and caused by the same phenomena that resulted in the salinity and temperature maxima in winter and the rises in the bottom isotherms in summer.

CONCLUSIONS

This study has shown the "Convergence" nature of the "Permanent Station" off Kaikoura, as subtropical and subantarctic water influenced the area all year round.

The fluctuating intrusions of subtropical water were subsurface in winter at the "Permanent Station", and isolated in time from one another by subantarctic water; but with the southward migration of the subtropical water in summer, its influence was recorded at the surface.

In winter the water column showed more coastal characteristics than it did in summer.

Other phenomena, the upwelling of warm water over the Conway Trough in winter (Houtman 1965), and upwelling cold water in the same place (Garner 1961) in summer, add to the complexity of the above situation. It is not impossible that an indication of the latter occurrence was recorded at the "Permanent Station" on at least 21 December '64.

The movements of water described here produced a high winter level of nitrate and enriched surface layers on at least two occasions: the end of September and 21 December 64.

C. THE PHYTOPLANKTON

There are many methods for estimating the concentration of phytoplankters in the sea, including cell counts, cell volumes and pigment extraction. Riley, Stommel and Bumpus (1949) pointed out the variability of all these methods. As only an indication of the phytoplankton seasonal cycle was required, the pigment extraction method was chosen because of its speed and consistency from one sampling day to the next. Chlorophyll a is the major chlorophyll in the phytoplankton, so chlorophyll a data alone are used.

There is no constant factor that may be used to convert the amount of chlorophyll to biomass, as the amount of organic matter associated with a given amount of chlorophyll varies with the species of phytoplankter and its stage of nutrition. A conversion factor, 1mg chlorophyll = 54mg carbon, was given by Riley et al (1949) but according to Strickland and Parsons (1960) this factor may vary between 20 and 70.

Methods

On each sampling day at the "Permanent Station" the bulk of the water, collected in the modified Van Dorn 5 litre water sampler, at 0, 10, 25, 50, 75, 125, and 200 metres' depth (see Page 4) was used for the extraction of plant pigments from the phytoplankton. The method employed was that of Richards with Thompson as modified by Strickland and Parsons (1960).

All samples taken before 16 August '64 were filtered through an HA Millipore filter (pore size 0·45μ), but as these filters tended to clog very quickly a change was made to the AA Millipore filter (pore size 0·8μ). Small flagellates may have been lost through this latter filter but the amount of pigment lost seemed insignificant beside the amount of pigment that was often not extracted. On 12 July

'64, particularly, it was noticed that all the pigment was not extracted from the phytoplankton. On this occasion examination of the net plankton showed that a bloom of *Ceratium* spp. had occurred. Gardiner (1943) has reported that *Ceratium* spp. were far from completely decolourised by 80% acetone. This genus was present to a greater or lesser extent over the whole sampling period.

An attempt to extract more of the chlorophyll was made on 11 October '64 by grinding the filter plus the phytoplankton with carborundum powder after freezing. The result from a duplicate sample was:

Chlorophyll *a* at the Surface on 11 October 1964	
After grinding with Carborundum Powder	Without grinding
2·7mg/m^3	2·4mg/m^3

The consistency of the above result could not be determined. This was because replicate samples could not be treated simultaneously as there was only one filter holder available. Even after grinding, complete extraction of the pigments was not achieved.

All samples filtered on or before 26 June '64 were stored in a dessicator and frozen before the pigments were extracted on 3 July '64. Thus the April and May 1964 samples were stored longer than the 4 weeks recommended by Humphrey (1960). All other filtered samples were not stored but treated immediately.

The extinction of the plant pigments dissolved in acetone was measured on the "Spectronic 20" colorimeter-spectrophotometer.

Secchi Disc readings were taken from 16 August '64 onwards.

In order to compare the results of this study with those of Ryther and Yentsch (1957), "gross" primary production was calculated from radiation, transparency and chlorophyll data by their method and using the equation:

$$Pd = Rd \cdot Cd \cdot 3{\cdot}7$$

where $3{\cdot}7$ = gm carbon assimilated per hour at light saturation for each gm of phytoplankton chlorophyll.

Pd = daily photosynthesis (gm carbon/m^3) at depth (d)

Rd = relative photosynthesis at depth (d) from Fig. 1 in Ryther and Yentsch (1957) for the appropriate value of surface radiation. Secchi Disc readings were used to indicate the rate at which the surface light intensity was reduced in the water column.

Cd = gm chlorophyll/m^3 at depth (d).

Radiation figures from Harewood Airport (Fig. 1) were used as a measure of surface radiation. They ranged from 49-667 g cal/cm^2/day on 12 July and 17 November '64, respectively.

Daily photosynthesis below a square metre of sea surface was then calculated by graphic integration of the values obtained for each depth.

This method assumes a constant assimilation number (photosynthesis / unit chlorophyll at optimal light intensity) and a constant and predictable relationship between photosynthesis at optimal light intensity and any other naturally occurring light intensity (Menzel and Ryther, 1960).

Results

Annual Cycle of Biomass as shown by Chlorophyll *a*

From Fig. 16 (mean amount of chlorophyll *a* in mg/m^3 from 4 depths above 50m) it may be seen that sampling was commenced when the last of the 1964 autumn phytoplankton growth had occurred. From then until 16 August '64 the mean amount of chlorophyll *a* remained at a minimum, ranging from 0·41mg/m^3 on 15 June '64 to 0·79mg/m^3 on 1 June '64.

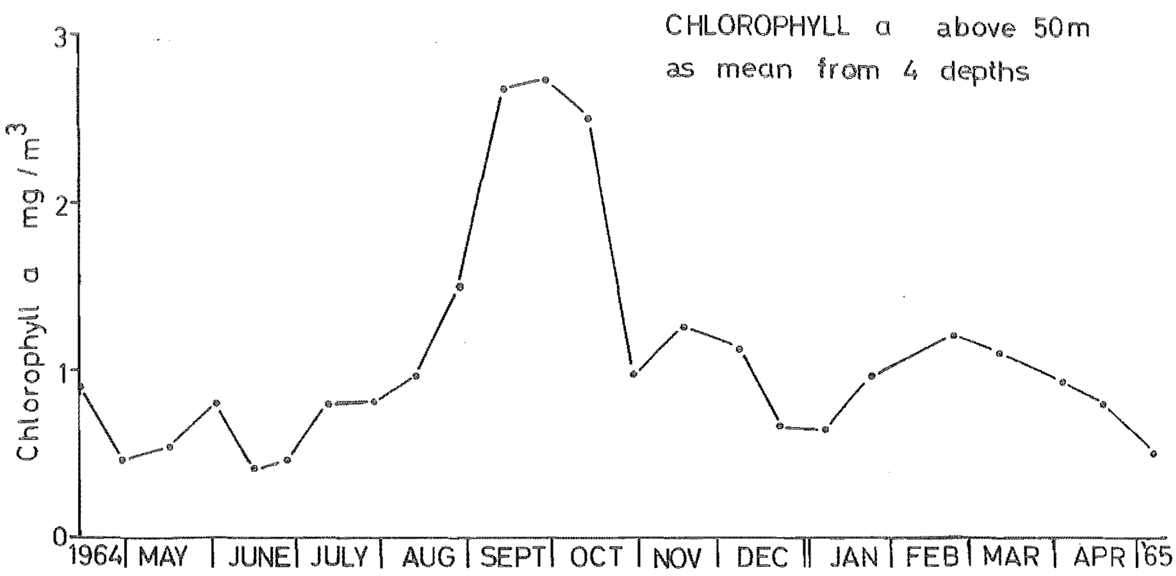


Fig. 16: Seasonal Cycle of Chlorophyll a mg/m^3 (mean of four depths) at the Kaikoura "Permanent Station", 1964-65

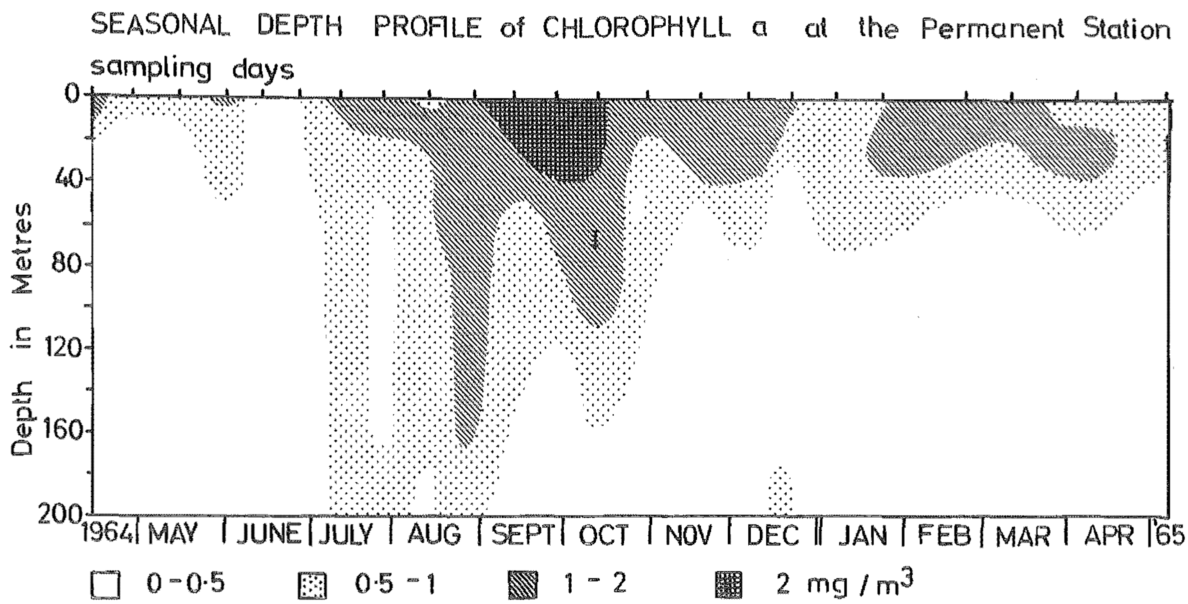


Fig. 17: Seasonal Depth Profile of Chlorophyll a (mg/m^3) at the Kaikoura "Permanent Station"

By 16 August '64 the mean amount of chlorophyll *a* started to increase, gradually at first, but then very steeply until a maximum amount, 2·74mg/m^3, was reached on 26 September '64. This peak concentration lasted for at least 4 weeks, followed by a sharp decrease to below 1·0mg/m^3 on 29 October '64. A small increase of about 4 weeks' duration followed this being succeeded by a drop to a minimum of 0·64mg/m^3 on 7 January '65. Another small peak amount of 1·20mg/m^3 occurred on 24 February '65. It is possible that this amount was exceeded between 24 January and 24 February '65 when no sample was taken.

The mean amounts of chlorophyll *a* found on 14 and 30 April (0·89 and 0·46mg/m^3 respectively) corresponded approximately to the amounts found one year later on 18 April and 5 May '65 (0·79 and 0·50mg/m^3 respectively).

Distribution of Chlorophyll a with Depth

Fig. 17 shows the seasonal depth profile of chlorophyll *a* at the "Permanent Station". In general a concentration greater than 0·5mg/m^3 of chlorophyll *a* was never found below 80m depth, except in the period from 12 July to 29 October '64. On 29 August '64 a concentration as great as 1·21mg/m^3 was found at 125m. This period, from 12 July to 29 October '64, corresponded to the whole space of time over which the spring phytoplankton bloom took place (Fig. 16).

An amount of chlorophyll *a* greater than 2mg/m^3 was found only over a period of at least 4 weeks. This occurred at the surface with a maximum concentration of 4·45mg/m^3 at 10m on 13 September '64.

The vertical distribution of chlorophyll depends to some extent on the depth to which light penetrates. Yentsch (1963) showed that the depth of the region of maximum photosynthesis indicated the depth of the euphotic zone (Table 2).

Table 3: Comparison of the two Methods for Determining the Depth of the Euphotic Zone

DATE	Depth from Secchi Disc Readings	Depth from Chlorophyll Maxima
1964 16·viii	18	45
13·ix	16	45
26·ix	19	45
11·x	17	45
29·x	13	45
7·xi	21	83
5·xii	27	83
21·xii	18	25
1965 7·i	36	45
24·i	27	83
24·ii	17	45
12·iii	12	25
4·iv	41	83
18·iv	17	83
5·v	9	45

Table 2 Depth of the Euphotic Zone (Yentsch 1963)

Depth of maximum Photosynthesis	Depth to which Photosynthesis occurs
3m	25m
5-10m	45m
10-20m	83m

Jitts (1965) has given data in which the chlorophyll maxima corresponded approximately to the productivity maxima for waters off Australia ranging from tropical to subantarctic. On this base, the photosynthetic maxima of Yentsch are equated with the chlorophyll maxima at Kaikoura and the depth of the euphotic zone is calculated by multiplying the Secchi Disc reading by three (Riley in Strickland, 1958). Table 3 compares the two methods.

From the adjacent figures it may be seen that the distribution of chlorophyll found at the "Permanent Station" was not a product of the transparency conditions recorded there by the Secchi Disc, except for perhaps 21 December '64 and 7 January '65. It appears that more transparent oceanic water had moved close to the coast and become overlaid and mixed with more turbid coastal water. This agrees with the hydrological data discussed in the previous section.

The spring bloom began in August when vertical mixing was in progress. (See Page 13) Thus the depth to which a chlorophyll concentration between 0·5 and 1·0mg/m^3 appeared from 12 July to 29 August '64, is explained.

Comparisons with Other Regions

Latitude and bathymetric depth have a great deal of influence on the type of annual phytoplankton cycle found. Colebrook and Robinson (1960), from their analysis of Hardy Continuous Plankton Recorded samples, distinguished several different types of phytoplankton and copepod annual cycles.

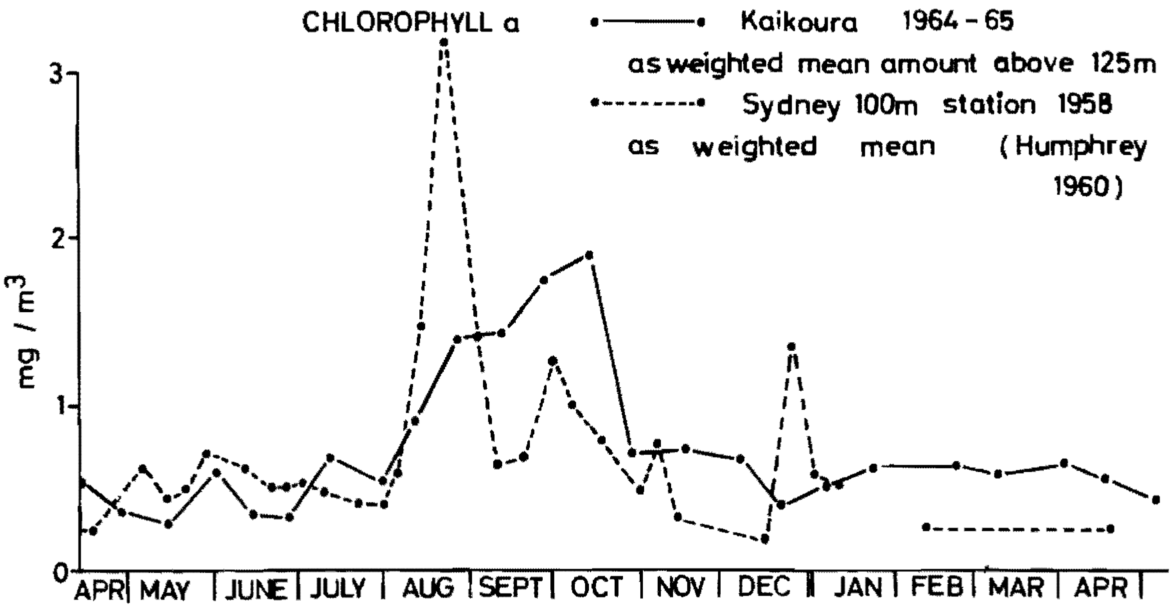


Fig. 18: Seasonal Cycle of Chlorophyll a, mg/m^3, as weighted mean off Sydney, 1958, and at the Kaikoura "Permanent Station", 1964-65

They showed that the plankton season was of longer duration over shallow water and the form of the cycle was often not of the classical type, i.e. with peaks in spring and autumn (Russell and Younge, 1949).

Ryther and Yentsch (1958), in their study of primary productivity off New York recorded that shallow inshore regions less than 50m depth had a higher yearly total productivity than offshore regions greater than 100m depth. They also demonstrated that the peak of production came a month earlier at 100-200m than offshore at depths greater than 1000m.

As it was hoped that, by comparisons, the effects of the complex hydrological situation would show up, areas were chosen for comparison with approximately the same depth and latitude.

a) Comparison with 100m Station off Sydney

Humphrey's (1960) cycle of chlorophyll a as the weighted mean amount at the 100m station off Sydney is compared with the cycle at the Kaikoura "Permanent Station" down to 125m in Fig. 18. The weighted mean concentration, X, above 125m was calculated from: $\frac{5C_0+12\cdot 5C_{10}+20C_{25}+37\cdot 5C_{75}+25(C_{50}+C_{125})}{125}=X$

where C_0, C_{10}, C_{25} .... were chlorophyll a concentrations at 0, 10, 25, ... metres respectively.

Beginning with April at the end of autumn, it may be seen that the amount of chlorophyll a in the two areas was approximately similar until the beginning of August. Then, at the Sydney 100m station, there was a rapid increase in chlorophyll a which reached a maximum concentration greater than $3mg/m^3$ in late August. There were only three weeks when the weighted mean amount of chlorophyll a was greater than $1\cdot 25mg/m^3$ at Sydney. On the other hand, at Kaikoura, the peak of $1\cdot 90mg/m^3$ was attained much more slowly but there was a space of six weeks, approximately, over which

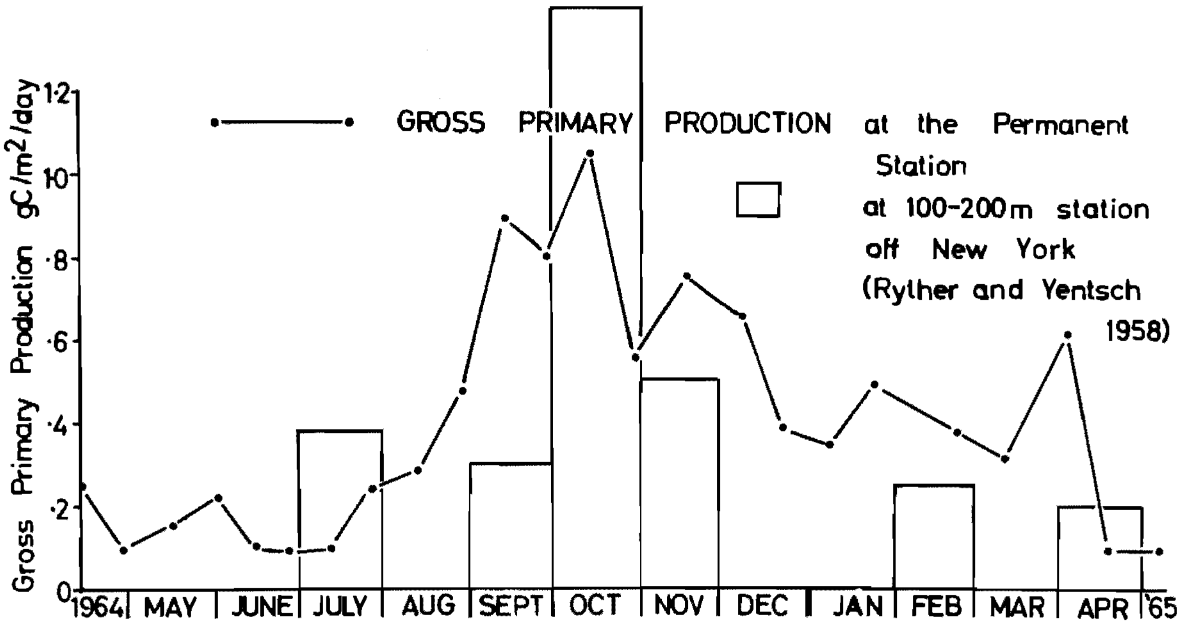


Fig. 19: Seasonal Cycle of "Gross" Primary Production ($g\ C/m^2/day$) off New York and at the Kaikoura "Permanent Station" 1964-65

Table 4: Primary Production (from Ryther and Yentsch, 1958)

	Total Depth in Metres	Production $gmC/m^2/year$
Long Is. Sound	25	380
Continental Shelf	25-50	160
	50-1000	135
	1000-2000	100
North Central Sargasso Sea	>5000	78
Kaikoura, N.Z.	200	157

an amount greater than $1{\cdot}25mg/m^3$ was found.

From September until December there was a consistently greater amount of chlorophyll a at Kaikoura than off Sydney. At the end of December there was a short sharp increase in chlorophyll a at Sydney. On the last 2 sampling days in February and April off Sydney only half as much chlorophyll a was detected as at Kaikoura.

b) Comparison of "Gross" Primary Production Calculated for Various Areas by Ryther and Yentsch with that Calculated for Kaikoura

"Gross" primary production at the "Permanent Station" calculated from chlorophyll, radiation and transparency data is compared with that of Ryther and Yentsch (1958) who used the same method (Fig. 19). The range of primary production found at Kaikoura was $0{\cdot}09$–$1{\cdot}05gmC/m^2/day$. These figures did not differ appreciably from the values, given by Ryther and Yentsch, of $0{\cdot}20$–$0{\cdot}85gmC/m^2/day$ for their inshore station and $0{\cdot}10$–$1{\cdot}10gmC/m^2/day$ for their offshore location. Even Riley's (1957) values for gross production in the Central Sargasso Sea of $0{\cdot}09$–$0{\cdot}89gmC/m^2/day$ have a similar range. Although the ranges may be similar, total annual production in different regions may be quite dissimilar (Table 4).

The "gross" annual primary production at the "Permanent Station" off Kaikoura was a little higher than the average value for a comparable position off New York which is at approximately the same latitude.

Discussion

It is unlikely that the surface light radiation is the main controlling factor in the commencement of the spring phytoplankton bloom at Kaikoura as the lowest mean surface radiation of $0{\cdot}09$ g $cal/cm^2/min$ which occurred on 12 July was three times larger than the critical value, $0{\cdot}03$ g cal/

cm^2/min, given by Ryther (1963) for plant production. The stability of the water column must therefore have played an important part in determining the time at which the phytoplankton standing crop began to increase at Kaikoura.

Although the peak concentration of chlorophyll a found at Sydney was over 1mg/m^3 greater than the concentration found at Kaikoura, it was sustained for only half the time. The earlier appearance and the magnitude of the spring pigment maximum at Sydney was probably due to the difference in depth between the two stations.

The relationship between the renewal of nutrients at the surface (Fig. 13) and the amount of chlorophyll a (Fig. 16) is not clear. The grazing of zooplankters influences the phytoplankton standing crop (or chlorophyll) greatly. It is probable that on 21 December '64 the drop in the amount of chlorophyll a (Fig. 16) was produced by the grazing of tremendous numbers (4425/m^3 at 20m) of *Calanus tonsus*. For the remainder of the time it is possible that the absence of great concentrations of zooplankton compared with Sydney (Fig. 22) could allow a fairly large biomass of phytoplankton to exist throughout most of the summer, although this "large" biomass was not sufficient to deplete the surface nitrate to the level found from September to December. The sustained nature of the spring chlorophyll a peak was most probably brought about by the renewal of nitrate at the surface in September and the lack of heavy grazing by zooplankters until October.

It is not possible to draw any definite conclusions from the present data on factors controlling the phytoplankton biomass at the Kaikoura "Permanent Station" during the course of this study.

Conclusions

The seasonal cycle of phytoplankton at Kaikoura, as indicated by the chlorophyll a concentration, shows one major peak from September to mid-October with no well defined second peak.

It appears that the stability of the water column played an important part in the establishment of the spring phytoplankton bloom. The retention of a peak amount of chlorophyll a during September to October may be accounted for by the surface renewal of nutrients in September and the lack of heavy grazing by the zooplankters. There was an increased amount of chlorophyll a from the end of January onwards at Kaikoura compared with Sydney, but even then the nitrate at the surface was never reduced to the level observed from the end of September to the beginning of December.

The amount of chlorophyll a and the gross primary production were comparable with other regions of the same depth and latitude.

The vertical distribution of chlorophyll a agrees with the hydrological data in that the region was influenced by offshore waters and that some vertical mixing was taking place through the first part of the spring increase of phytoplankton.

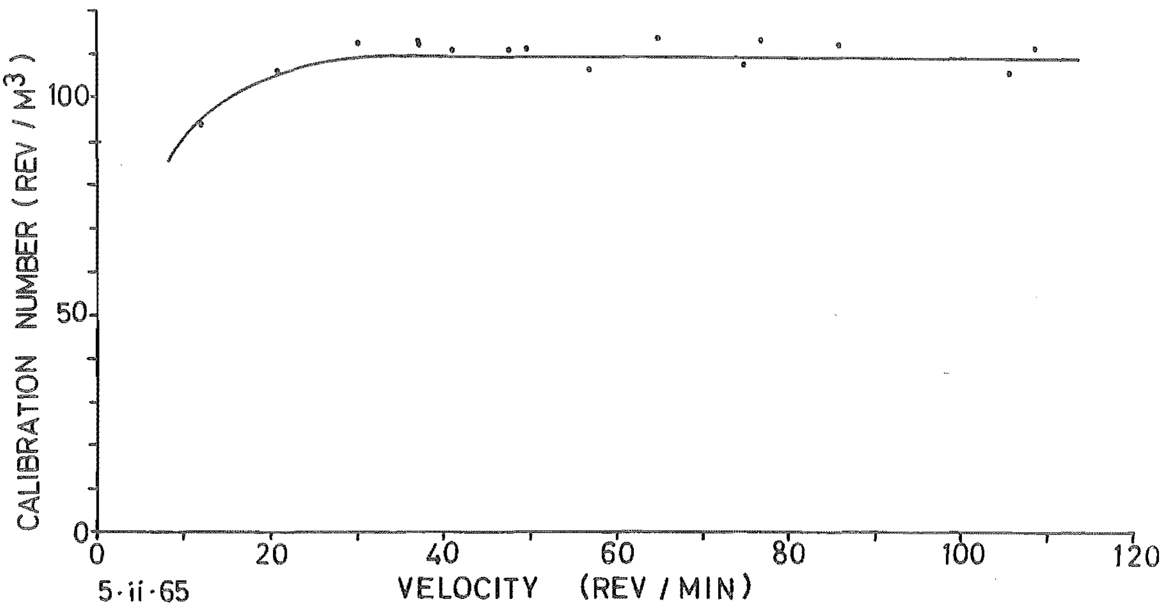


Fig. 20: A Typical Calibration Curve for the Clarke-Bumpus Sampler

D. THE ZOOPLANKTON

Methods

During the course of this study two nets were used to capture zooplankton. These were a Discovery N70 net and a Clarke-Bumpus sampler. (See Pages 4 and 5) The N70 net was used on each sampling day to take a vertical haul which served as a source of expendible animals for identification.

The Clarke-Bumpus sampler is well suited to quantitative work as it is fitted with an opening-closing mechanism and a flow meter. The flow meter was calibrated approximately once every 3 months, using a forced flow through the barrel of the sampler into a calibration pit. A calibration curve (Fig. 20) was obtained by plotting the number of cyclometer revolutions (rev.)/m^3 against rev./minute. The calibration error was about 5% and increased slightly before recalibration when the flow meter had become sluggish. Each Clarke-Bumpus sampler haul was made at a speed of about 2 knots so that the flow meter would revolve at a rate greater than 40 rev./min. This ensured that the calibration number used was found on the flat part of the calibration curve (Fig. 20). The amount of water that had been filtered during a haul was calculated by dividing the number of revolutions the cyclometer had made by the calibration number.

The aim of this part of the study was to estimate the quantity of zooplankton at the "Permanent Station". As it is difficult to separate phytoplankton from zooplankton, a net was chosen with an aperture size small enough to catch most adult copepods but large enough not to catch the phytoplankton. The net used had 72 meshes to the inch and an aperture width of 176 microns. When a catch from the Clarke-Bumpus sampler was compared with the fine net samples (Page 5) it was clear that the former net lost a large portion of the smaller zooplankton through its meshes. This loss is not taken into account as comparisons will be made with figures from other workers who have used nets with similar aperture sizes.

Sampling of the zooplankton was begun on each sampling day between the times of 8.30 and 10a.m., except on 21 December '64 when sampling was commenced at 3.30p.m. The effects of diurnal vertical migration are ignored for the purposes of this study as many planktonic animals reach a maximum depth in their migratory cycle on either side of mid-day(Marshall and Orr, 1955; Raymont, 1963).

Two types of haul were made with the Clarke-Bumpus sampler, an oblique haul and four horizontal hauls. The time available permitted only one of each type of sample to be taken. The variation of a single haul will be discussed in the following sections with reference to other workers, and one set of replicate samples taken during this study.

Oblique Haul

An oblique haul was taken on each sampling day by letting out the net on enough wire, while the boat was moving at about 2 knots, for the 55lb weight to take the net down to 200m. A messenger was sent down to open the net and the wire hauled in at a constant speed that allowed the haul to last 10-15 minutes. A record was taken of the number of revolutions the cyclometer had made. This number was divided by the calibration number to determine how many cubic metres had been filtered. As it was found that the Tunicate, *Pyrosoma*, often became wrapped round the wire, preventing a messenger from triggering off the opening-closing mechanism of the Clarke-Bumpus sampler, a double oblique haul was taken from the 16 August, instead. That is, the net was sent down open so that it sampled on the way down as well as on the way up. The volume filtered was between 5 and 12 cubic metres.

The oblique haul was chosen in preference to the vertical haul as Windsor and Clarke (1940) found that the coefficient of variation of a single vertical haul was 53%, while the coefficient of variation of a single oblique haul was 31%. A maximum variation of 50% was found by Tranter (1962) when he weighed oblique haul samples taken over a period of 48 hours. During this study on 14 April '64, six consecutive hauls were taken from 100m and various groups were counted by the method outlined on page 30. The coefficient of variation of a single haul as determined by the method used by Windsor and Clarke (1940) was 30%, which is very similar to their result.

The total zooplankton collected during an oblique haul was used to determine a) wet weight or biomass, b) dry weight and c) organic matter content of the zooplankton for each sampling day. The methods by which these data were calculated are described below.

a) <u>Wet Weight or Biomass</u>

The wet weight was determined by filtering the zooplankton under suction, on to No. 42 Whatman ashless filter paper (5cm diameter) while rinsing with 70% alcohol. A similar method was used by Harris and Riley in Riley et al (1956). This method was chosen as after wetting, removal of excess moisture and weighing six times, a coefficient of variation of 1·47% was gained. Nakai and Honjo (1961) did not use a suction pump but rolled the plankton on filter paper to remove the excess moisture. This method gave coefficients of variation ranging from 0·31 to 2·01%. The method used during this study compared favourable with these results. The method Tranter (1962) used to separate his zooplankton samples from their preservative was tested. He used a perspex weighing dish fitted with a bottom of fine gauze to drain off the liquid. The sample was washed with 50% alcohol and the excess moisture removed by standing the weighing dish on filter paper for a few minutes. Tranter himself gained coefficients of variation ranging from 0·57 to 7·56% after weighing six samples six times, while during this study this same method gave coefficients of variation of 6 and 11%, so this method was discarded in favour of the one first mentioned which gave a coefficient of variation of 1·47%.

The zooplankton on the filter paper was rinsed with 70% alcohol and left under suction until the alcohol had stopped visibly vapourising under the glass filter holder. The zooplankton sample plus the damp filter paper was then placed in a porcelain crucible and weighed on a Mettler H15 balance to 4 decimal places. By subtracting the weight of the crucible plus the damp filter paper (both pre-determined) from the above weight, the wet weight of the zooplankton was found.

When large specimens occurred, for example Euphausids larger than 1·5cm length and salps, they were removed and processed separately.

The use of the Whatman No. 42 ashless filter paper had its advantages and disadvantages. The advantage was in the ashing of the sample, whereas the hygroscopic nature of the filter paper made it difficult to gain constant weight after drying the zooplankton sample.

b) Dry Weight

The crucible used for the wet weight determination with its contents was then dried in an oven at 95°C. This was the temperature used by Harris and Riley in Riley et al (1956) and Nakai and Honjo (1961). By subtracting the dry weight of the crucible plus the dry weight of the filter paper from the above weight the zooplankton dry weight was determined. The results obtained may be too low as Curl in Lovegrove (1962) suggested that drying the zooplankton at temperatures higher than 80°C would volatilise some lipids and amines as well as denature some proteins.

c) Organic Matter Content

The contents of the crucible were then ignited to constant weight in a muffle furnace at 900°C. The ash weight was found by subtracting the weight of the crucible from the above weight. When the ash weight was subtracted from the dry weight an estimate of the organic matter content of the zooplankton was obtained. It is probable that these (organic matter) values are too large as Curl in Lovegrove (1962) states that ashing above 450°C would volatilise bicarbonates.

Horizontal Haul

Four horizontal hauls were taken each sampling day at about 5, 22, 70 and 120 metres' depth (see Page 4). The hauls were made at a speed of about 2 knots and the number of revolutions the cyclometer made were noted. The volume filtered was between 5 and 15 cubic metres. As the author was unable to replicate exact conditions in consecutive hauls no attempt was made to determine the variation involved during this study. Much of the variation found in other studies probably arose from apparent strong vertical stratification of the zooplankton. Windsor and Clarke (1940) gave one such explanation for the 93% variation they recorded for a single haul.

The numbers in the main taxonomic groups were counted in the horizontal samples. Molluscs, Polychaetes, Ostracods and some other larvae are not recorded here as they were never very abundant. Most of the samples were too large to count entirely, so the sample divider of Kott (1953) was used (Fig. 7). She found that small differences in compartment size had no connection with the differences in plankton counts for each compartment, and that there was a tendency for some animals to "clump", especially when they were present in large numbers. The sample divider made for this study was put through the same tests and was found to have

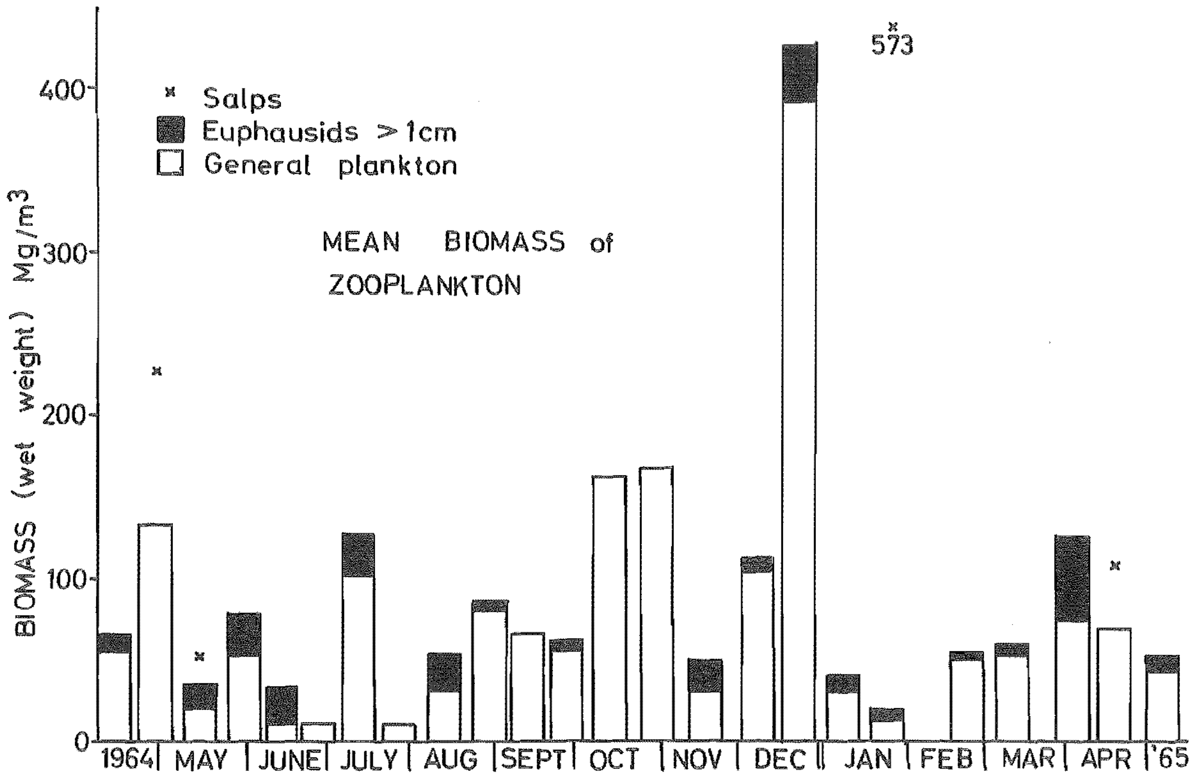


Fig. 21: Seasonal Cycle of Mean Zooplankton Biomass (wet weight mg/m^3) captured in oblique hauls from 200m at the Kaikoura "Permanent Station", 1964-65

the same characteristics. However, Kott concluded that the variations were well within the limits of accuracy required and achieved with the present methods of collecting plankton. A fraction, usually 1/10th, of the sample was counted on a perspex tray 8cm by 3cm marked in 5cm squares. Note was also taken of the rarely occurring species.

Results a

BIOMASS

The biomass of zooplankton in mg/m^3, omitting Salps, (Fig. 21) fluctuated greatly during the period of sampling. The lowest amount of 10·3mg/m^3 occurred on 2 August '64 and the highest amount of 403·1mg/m^3 on 21 December '64. But there was no steady rise and fall. On two occasions, late autumn and winter, amounts greater than 100mg/m^3 were recorded, but it was not until October that the burst of zooplankton growth in answer to the August-September phytoplankton bloom occurred. In November the amount dropped to below 50mg/m^3, and was followed by a rise to a peak concentration of 403·1mg/m^3 which occurred on 21 December '64. This zooplankton increase was entirely due to the presence of huge numbers of stage V Calanus tonsus copepodites at 5m on 5 December and at 22m on 21 December '64. On both occasions they must have been concentrated in a narrow band as on the latter date a biomass of 6200mg/m^3 was found at 22m. This tremendous biomass of copepods must surely have hampered the growth of the phytoplankton population at the surface. In January there was a very sharp drop in the amount of zooplankton and it was not until 4 April '65 that an amount greater than 100mg/m^3 was recorded.

Over the whole year a mean amount of 68mg/m^3 was recorded.

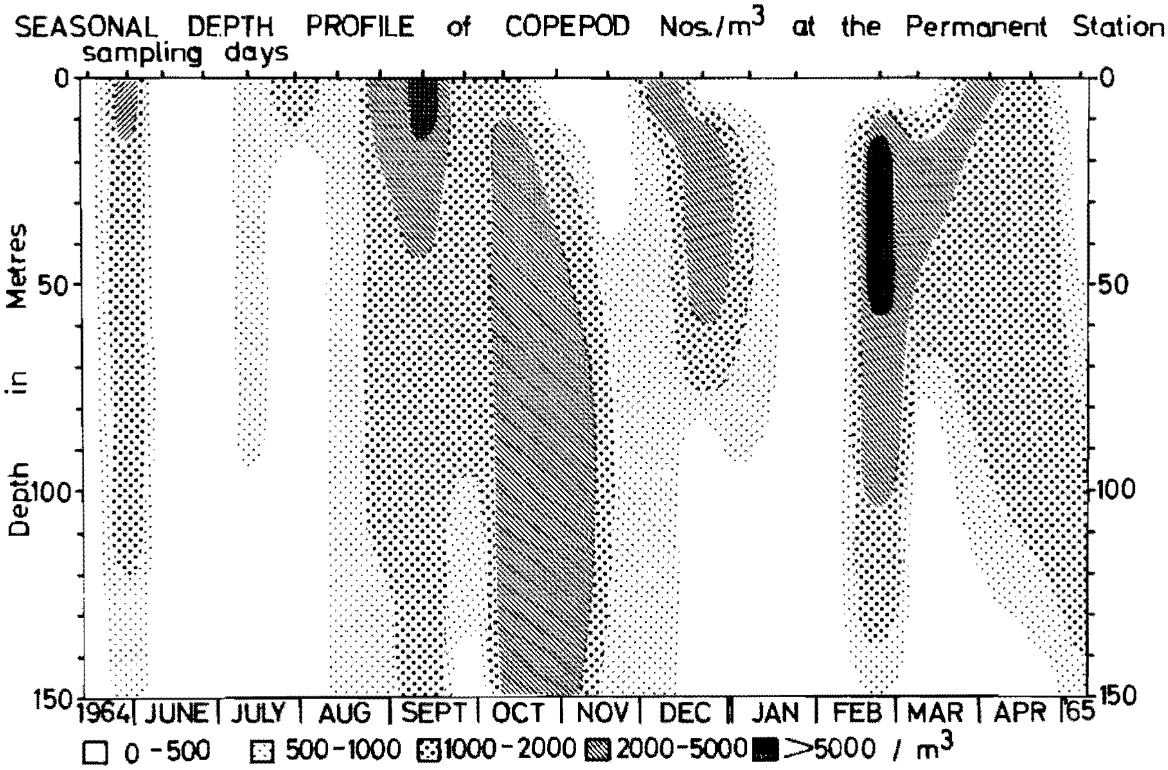


Fig. 31: Seasonal Depth Profile of Copepoda numbers/m^3 at the Kaikoura "Permanent Station", 1964-65

Comparisons with Other Regions

The main comparison of this study will be made with the results of Tranter (1962) as his samples were taken in the same way at the 100m station at Port Hacking, Australia. The net he used was slightly coarser; 62 meshes to the inch and 0·26mm apertures. (It will be seen that this difference will not affect the overall conclusions.) Although the Port Hacking station was further north and shallower the hydrological situation seems to be somewhat similar to that off Kaikoura in summer. Humphrey (1960) recorded invasions on warm surface waters at intervals.

In Fig. 22 the total cycles of zooplankton biomass at the Port Hacking 100m station and the Kaikoura "Permanent Station" are compared. The salp biomass is included in these figures except on 24 February '65 at Kaikoura when the total salp biomass was contributed by only two large Salpa sp. The concentration of zooplankton at Port Hacking was consistently greater than at Kaikoura (Fig. 22). This difference is shown more clearly in the average annual biomass which at Sydney (151mg/m^3, without Salps) was twice that at Kaikoura (68mg/m^3). The fact that the nets used during this study were catching more of the zooplankton than the nets Tranter used makes the above discrepancy more significant.

It is recognised that tropical regions are less productive than polar regions (average standing crop 0-50mg/m^3 and 1000mg/m^3 respectively) although the equatorial divergence modifies this picture (100mg/m^3). These figures are from Tranter (1962) who summarises the distribution of zooplankton over different oceanic areas. Coastal areas are also more productive than adjacent oceanic areas. For example, Tranter (1962), during the period November to April, found a biomass of 25-50mg/m^3 adjacent to the south east coast of Australia, while further off shore a biomass less than 25mg/m^3 was recorded. The average biomass for the "Permanent Station"

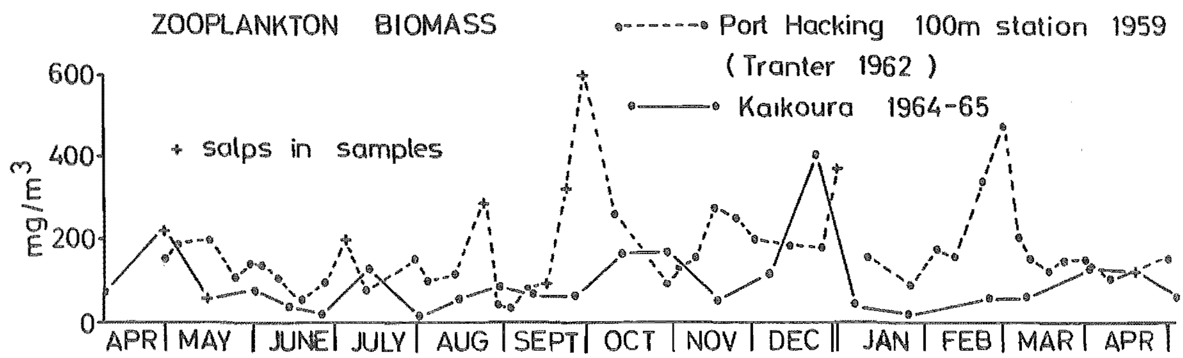


Fig. 22: Seasonal Cycle of Mean Zooplankton Biomass (wet weight mg/m^3) at Port Hacking, 1959, and at the Kaikoura "Permanent Station", 1964-65

off Kaikoura of 68mg/m^3 appears to agree with the values of 0-50mg/m^3 given by Russian workers Ponamarev and Lubini, and Bogorov and Vinogradov in Tranter (1962) for the north and south subtropical zones.

DISCUSSION

It is not to be expected that the zooplankton biomass found at Kaikoura with its narrow continental shelf (Fig. 2) would be the same as that found at areas with an extensive continental shelf. For example, an average biomass of 247mg/m^3 was found in Block Island Sound by Deevey in Riley et al (1952). The fact that the Kaikoura "Permanent Station" had a lower average biomass than the Port Hacking 100m station may be attributed to either the difference in depth between the stations, or the disturbed hydrography in the form of warm water invasions, supposed upwelling, and other summer water movements.

Coastal waters, less than 100m depth, are characterised by nutrient enrichment during the summer while oceanic surface waters tend to be continually depleted of nutrients at the same time. When the nitrate concentrations are considered (Fig. 13) it is clear that the "Permanent Station" did not follow a pattern of continuous nutrient depletion. Thus the difference in depth between the Sydney 100m station and the Kaikoura "Permanent Station" could not have been the reason for the low biomass observed at Kaikoura.

It would seem probable that the disturbed hydrology, especially in summer, was responsible for the low biomass at the "Permanent Station".

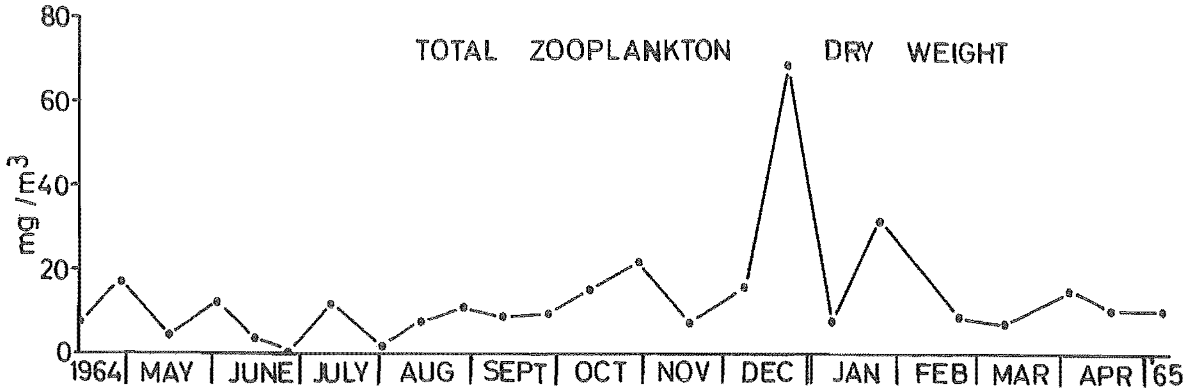


Fig. 23: Seasonal Cycle of Zooplankton Dry Weight (mg/m^3) at the Kaikoura "Permanent Station", 1964-65

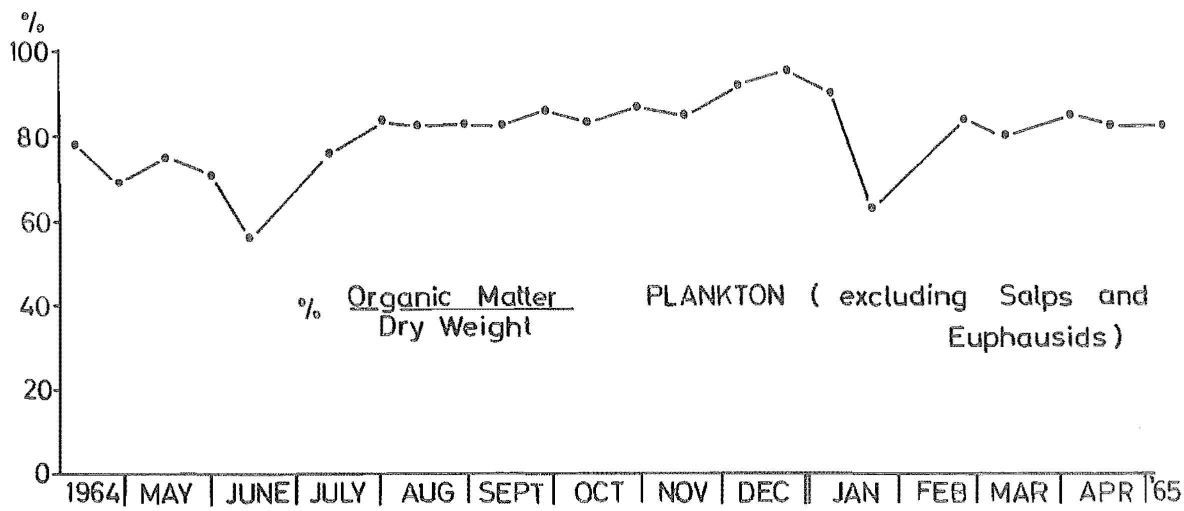


Fig. 24: Seasonal Cycle of $\% \frac{\text{Organic Matter}}{\text{Dry Weight}}$ of Plankton (excluding Salps and Euphausids) at the Kaikoura "Permanent Station", 1964-65

Influence of Separate Species on the Biomass, and Organic Matter Content of the Zooplankton

From figures obtained during this study and those given by Riley and Gorgy (1948) it is obvious that different species contain different amounts of water.

	% $\frac{\text{Dry Weight}}{\text{Wet Weight}}$
Riley and Gorgy	
Tunicates	1·7
Pteropods	38·6
Euphausids	10·7
Sagittae	13·4
Copepods	17·3
Misc. small crustacea	9·5
Kaikoura	
Salps	6
Euphausids	12
Calanus tonsus (Copepoda)	19
Plankton Misc.	14

The dry weight by itself is supposed to be a more meaningful measure of "biomass" as it is shown above that heavy salps do not represent a great amount of organic matter in the plankton. This appears to be correct for Kaikoura. Peaks caused in the wet weight (Fig. 21) by salps are depressed in the dry weight (Fig. 23), especially on 24 January '65. Tranter (1962), on the other hand, found that salp swarms he recorded represented a high concentration of organic matter and were evident as peaks in both wet and dry weights.

Organic matter is very important when the zooplankton is being considered as a source of food. As water is found in varying proportions in different species, the seasonal cycle or organic matter in the zooplankton is best described by expressing it as a percentage of the dry weight. Fig. 24 shows the manner in which the % $\frac{\text{Organic Matter}}{\text{Dry Weight}}$ varied. Winter values were below 80% with a minimum of 56% while the

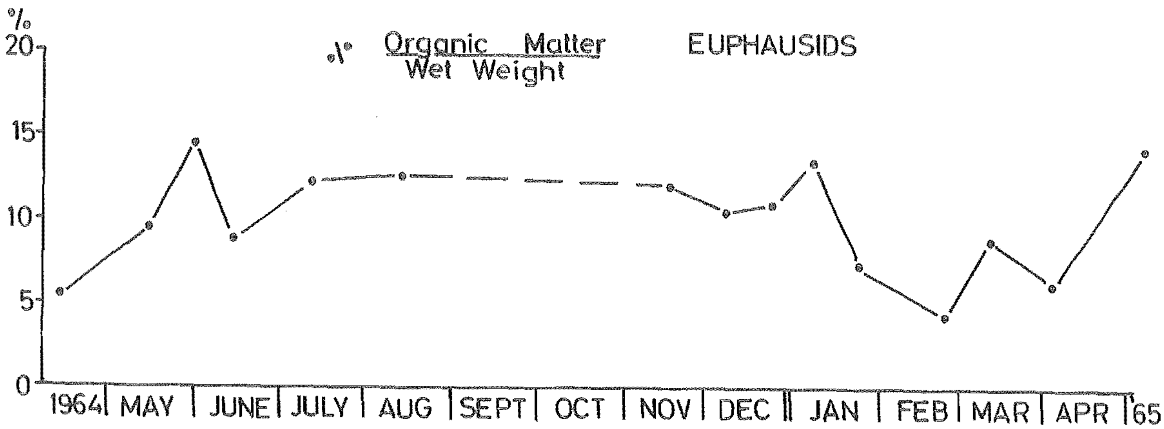


Fig. 25: Seasonal Cycle of % $\frac{\text{Organic Matter}}{\text{Wet Weight}}$ of Euphausids at the Kaikoura "Permanent Station", 1964-65

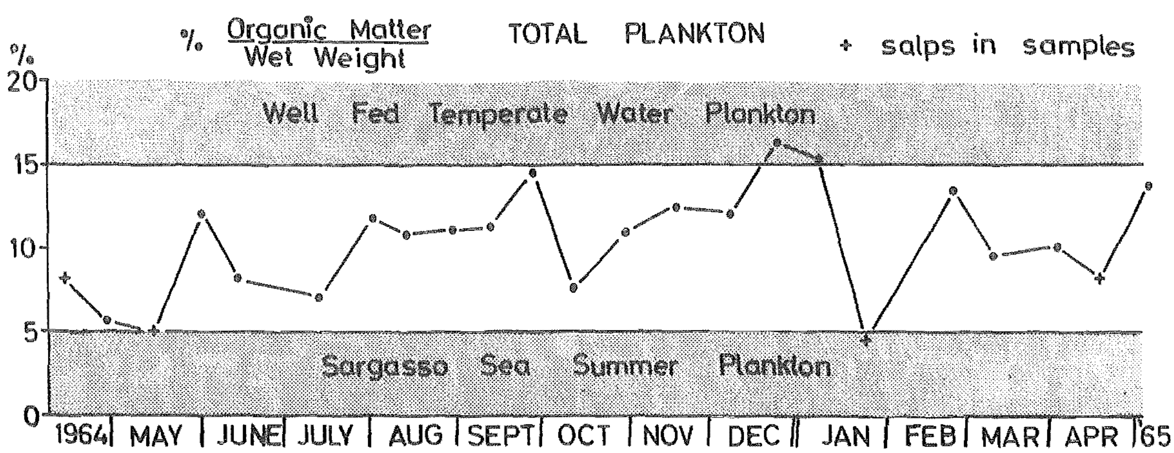


Fig. 26: Seasonal Cycle of % $\frac{\text{Organic Matter}}{\text{Wet Weight}}$ of Total Plankton at the Kaikoura "Permanent Station", 1964-65

remaining values were above 80%, except on 24 January '65. A summer maximum of 96% was reached on the 21 December '64. These values are an indication of the condition put on by most animals during the spring and summer when the food supply was good. Fat reserves are the form in which most of the organic matter is found (Riley et al, 1949). Marshall and Orr (1955) found an increased fat content in males, females and stage V Calanus finmarchicus copepodites in April which flattened out at the end of July. They also reported a maximum fluctuation in the percentage fat of 20% in males and stage V and 13% in females.

Several workers have related organic matter content to wet weight. As long as single species or plankton samples of similar species composition are referred to, valid comparisons may be made. The latter proviso usually holds except on those occasions when swarms of certain animals are encountered. Nakai (1942) determined the fat content of 7 Copepod and 3 Euphausid species covering latitudes from 32°22' to 42°22'N in the vicinity of Japan. His results were interpreted by Riley and Gorgy (1948) as showing a latitudinal effect on the amount of fat stored by different crustacean species although they state that there was no overlap of species in the regional groups. Thus it is possible that temperature does have an effect on fat storage. In Fig. 25 there were 3 occasions (in April to May, and June '64, and January to April '65) when the % $\frac{\text{Organic Matter}}{\text{Wet Weight}}$ of the Euphausids was below 10%. These instances, except perhaps 15 June, were also occasions when subtropical water was influencing the "Permanent Station" (Fig. 14). Sheard in Thompson (1942) also noted that there appeared to be an increase southwards in the south-east Australian region in oil content of certain Copepods and Euphausids species (Euphausia similis, E. recurva and Thysanoessa gregaria). On the basis of the interpretation of Riley and Gorgy and Sheard's observations it appears that on certain occasions subtropical water may have carried Euphausids from the north into the vicinity of Kaikoura.

Riley et al (1949) used the $\% \frac{\text{Organic Matter}}{\text{Wet Weight}}$ to define zooplankton from different types of environment. They gave limits for the Sargasso Sea and well-fed coastal plankton as extremes, with slope water plankton between. In Fig. 26 these limits have been drawn on to the seasonal graph of the $\% \frac{\text{Organic Matter}}{\text{Wet Weight}}$ for the Kaikoura zooplankton. Nearly all the Kaikoura figures lie in the intermediate zone between the upper limit for Sargasso Sea plankton and the lower limit for well-fed temperate water plankton, except in December when the sample contained a large proportion of the copepod Calanus tonsus and on 16 May '64 and 24 January '65 when salps occurred in the samples. If, as previously pointed out (Page 30), the organic matter content values were too large it seems likely that the percentage error is small because of the agreement with the results of Riley et al (1949).

CONCLUSIONS

The average biomass of 68mg/m^3 found at the "Permanent Station" was low when compared with the biomass found at inshore stations of some North American workers and Tranter's Port Hacking, Australia, station, but agreed with figures 0-50mg/m^3 for subtropical oceanic regions. As the nitrate data seem to suggest that the depth of the "Permanent Station" was not responsible for the low biomass, it is possible that the disturbed hydrological situation had some effect on the animal populations. The chlorophyll a data support this latter hypothesis as it is probable that the phytoplankton concentration could have fed a greater zooplankton population than was recorded from the beginning of 1965.

Some zooplankton species, especially salps, contain more water than other species and they increase the biomass out of proportion to their organic matter content (Fig. 21). Dry weight measurements negate this inconsistency at the "Permanent Station" (Fig. 23) as no salp swarms were encountered.

At different times of the year the zooplankton had a varying organic matter content. This may have been a result of seasonal effects (Fig. 24) or in the case of the Euphausids (Fig. 25) a result of the origin of the water mass they inhabited.

The zooplankton as characterised by $\% \frac{\text{Organic Matter}}{\text{Wet Weight}}$ was typical of slope water plankton as defined by Riley et al (1949) except in December '64 and January '65.

Results b

ZOOPLANKTON NUMBERS

The results from the enumeration of the zooplankton will be presented in two forms: as mean numbers/m^3 and as % distribution with depth. The data on the graphs presenting the yearly cycle of numbers have been obtained by meaning the numbers/m^3 from 4 depths (approximately 5, 22, 70 and 120 metres). The horizontal hauls from which the numbers of animals have been counted have an inherent variability which has been discussed previously (Page 30). Thus reservations must be placed on drawing conclusions that are too detailed from these figures. Figures representing % distribution with depth are based on information from the above four depths. The sum of concentrations at each of these depths represents 100%. Distribution outside the sampling range of depths has not been considered.

Animals from the following groups were identified from the publications in brackets: Ctenophora (Benham, 1906; and Ralph and Kaberry, 1950); Copepoda (Wilson, 1932; Rose, 1933; and Fiches D'Identification du Zooplancton); Amphipoda

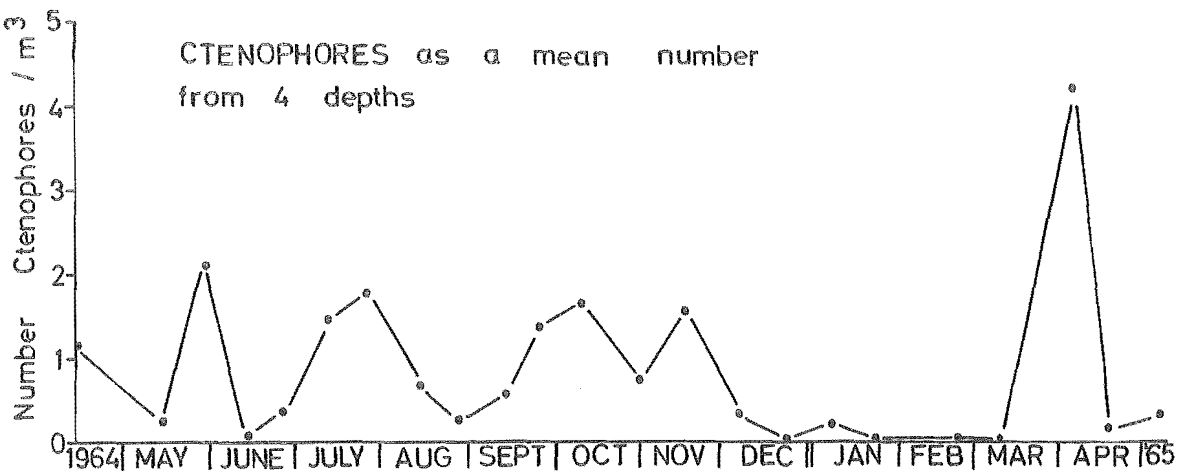


Fig. 27: Seasonal Cycle of Ctenophora numbers/m^3 (as mean from four depths)at the Kaikoura "Permanent Station", 1964-65

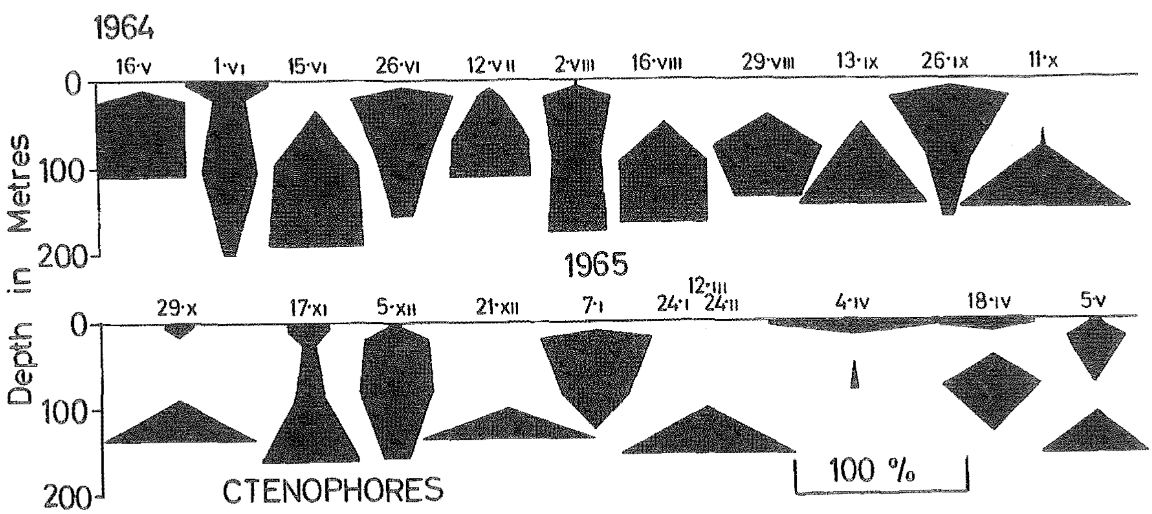


Fig. 28: Distribution of Ctenophora with Depth at the Kaikoura "Permanent Station" 1964-65

(Hurley, 1955); Euphausiacea (Sheard, 1953); Chaetognatha (Thompson, 1947; and David, 1955); and Tunicata (Thompson, 1948).

Ctenophora

Representatives of this group were not well preserved as they were often broken into unrecognisable pieces; thus they were difficult to identify and count. The most abundant species was Pleurobrachia pileus (O. F. Muller, 1776) which occurred all year round while P. australis (Benham, 1907) was found only in October, November and December '64. No other species were recognised but were possible present as Ralph and Kaberry (1950) recorded at least seven species from Cook Strait.

The numbers of Ctenophora/m^3 fluctuated during the year (Fig. 27). The most noticeable feature of the cycle was the almost complete absence of these animals in December '64, January, February and part of March '65. Ctenophora are feeble swimmers and are easily aggregated by tides and currents into dense swarms (Hyman, 1940) so the increases in numbers demonstrated during the course of this study may not necessarily have been increases in the general Ctenophora population.

Fig. 28 shows the percentage distribution with depth of the Ctenophora. It is evident that this group is found in its greatest numbers most often below 100m and is only occasionally found at the surface during the day. This agrees with the fact that all Ctenophora are of carnivorous habit; even large Euphausiacea were found in the guts of the specimens taken in this study.

Copepoda

This group represents the bulk of the zooplankton. The most plentiful species were:

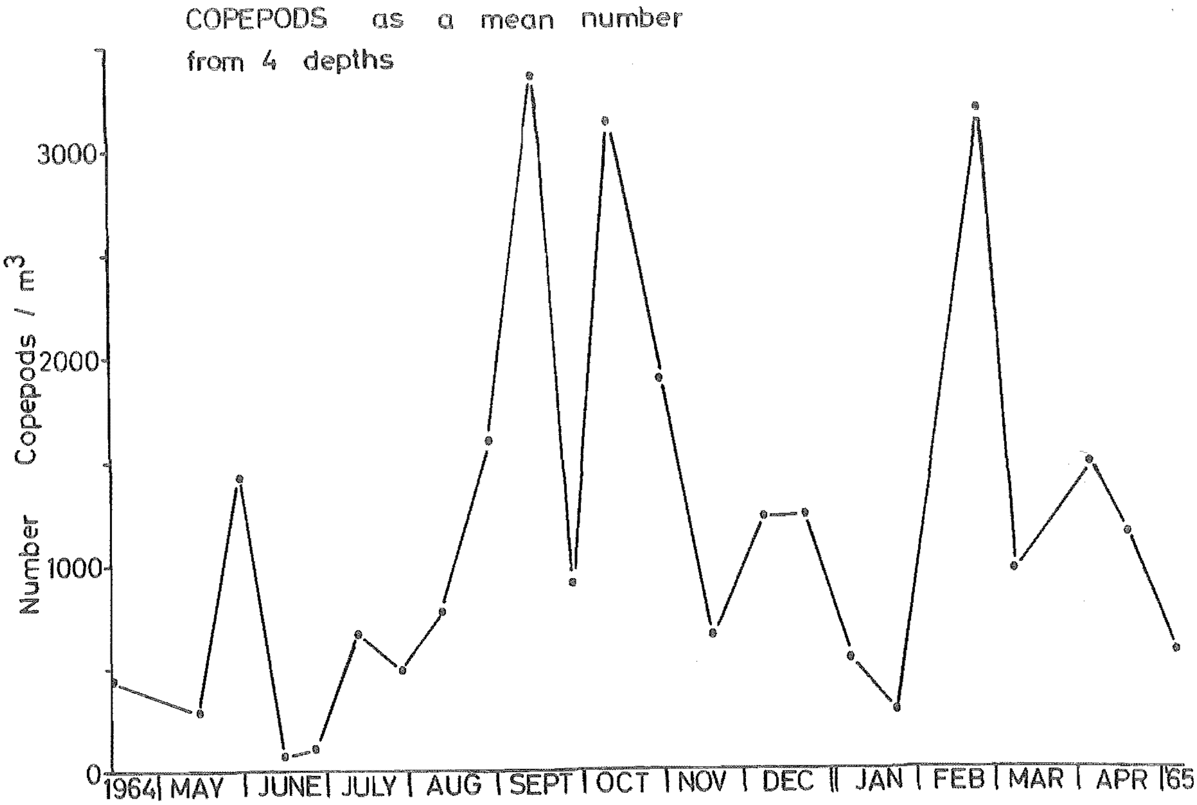


Fig. 29: Seasonal Cycle of Copepoda numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station", 1964-65

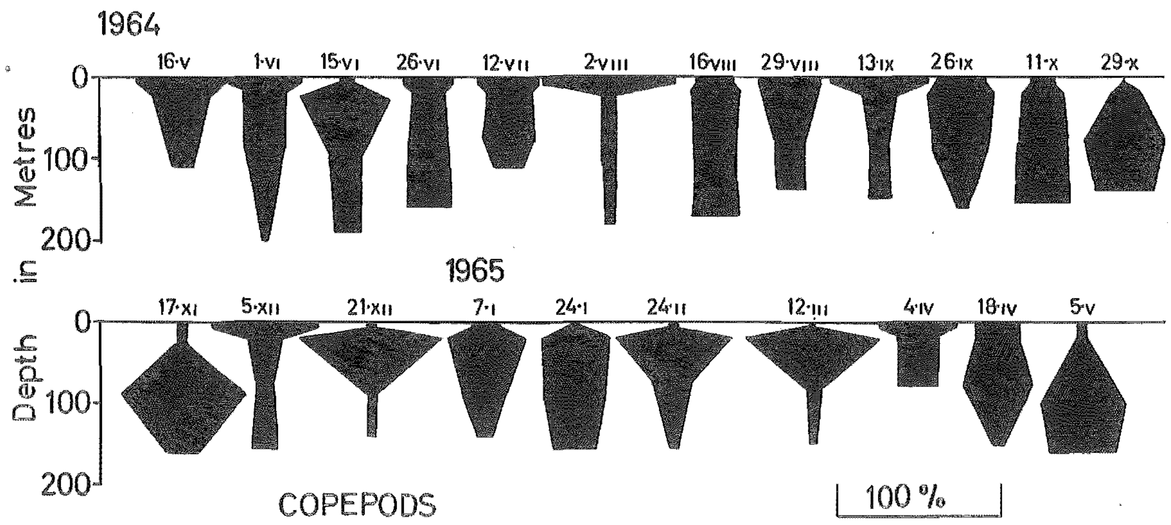


Fig. 30: Distribution of Copepoda with Depth at the Kaikoura "Permanent Station", 1964-65

Acartia clausi Giesbrecht, 1889
Oithona plumifera Baird, 1843
Oithona similis (Claus, 1863)
Centropages aucklandicus Kramer, 1892
Calanus australis Brodsky, 1959
Clausocalanus sp.
Clausocalanus arcuicornis (Dana, 1849)
Paracalanus parvus (Claus, 1863)
These species were found nearly all year round while the genera Acartia and Oithona were particularly abundant at the surface. Other more rarely occurring Copepoda will be discussed in a later section.

The numbers of Copepoda/m^3 fluctuated greatly during the year. The greatest numbers occurred in September, October and February but the period during December when the greatest biomass was found (Fig. 21) is represented in Fig. 29 by a relatively low number of Copepoda/m^3. The large Copepod Calanus tonsus, length 4mm, was present in a narrow band at this time. It is obvious that the size of an animal has considerable effect on the biomass as conversely when the small Oithona spp. (length 1mm) and Acartia clausi (length 1mm) were present in large numbers near the surface, there was no corresponding high biomass recorded. Fig. 30 shows that the maximum number of Copepoda is nearly always found at or near the surface. This is what would be expected of a group of animals that are mostly herbivorous.

From the distribution of numbers with depth (Fig. 31) it may be seen that concentrations of less than 500/m^3 were found on several occasions. From June to the beginning of August low numbers were associated with the main winter mixing process. The other occasions when low numbers of Copepoda were recorded (November, at the surface, December below 90m and January throughout the water column) were associated with invasions of warm water at the surface, the upwelling of cold water at the end of December and the disturbances during the period following this. Small numbers of Copepoda were also found nearer the bottom during March and April.

The short term fluctuations in the mean numbers recorded at Kaikoura were similar to those noted by Tranter (1962). He regarded the fluctuations as being indicative of instability in the environment. Thus it appears that any instance of instability in the environment resulted in reduced numbers of Copepoda. Tranter also found some slumps in the numbers of Copepoda were associated with Salp swarms. A parallel situation was found at the "Permanent Station" in May '64 (Fig. 21).

From information obtained during December '65 it is obvious that the swarms of <u>Calanus tonsus</u> that occurred then and one year earlier were important as food to the schools of Basking Sharks (<u>Cetorhinus maximus</u>) that were recorded near the Kaikoura Peninsula on both occasions.

Amphipoda

The main species of Amphipoda present with their seasonal occurrences are shown in the following table:

'64	A	M	J	J	A	S	O	N	D /	J	F	M	A	M '65
<u>Parathemisto australis</u> Stebbing, 1888	x	x	x	x	x	x	x	x	x	x	x			
<u>Parathemisto gracilipes</u> (Norman, 1869)			x							x			x	
<u>Vibilia stebbingi?</u> Behn and Wolt, 1912	x	x											x	
<u>Primno macropa</u> Guer, 1836				x		x					x			
<u>Phronima sedentaria</u> (Forsk, 1775)				x	x								x	x
<u>Cyllopus magellanicus</u> Dana, 1853	x	x								x			x	

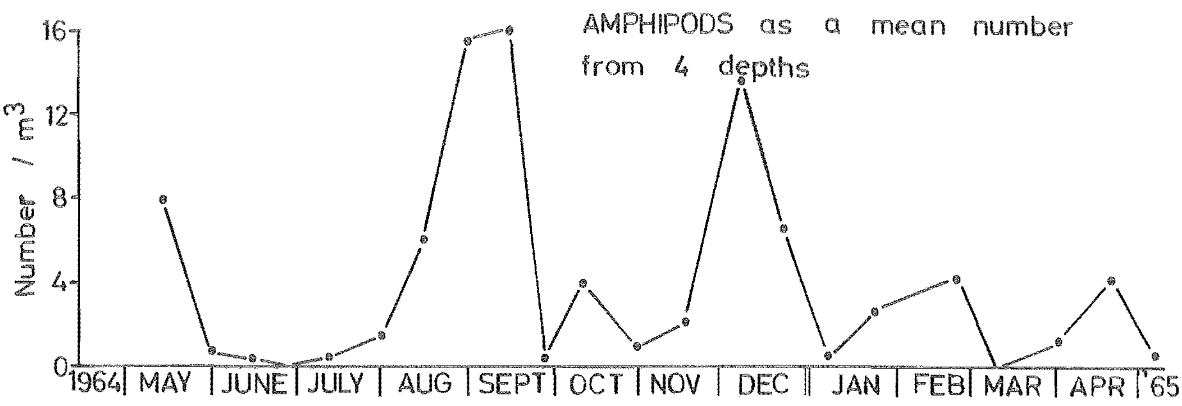


Fig. 32: Seasonal Cycle of Amphipoda numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station", 1964-65

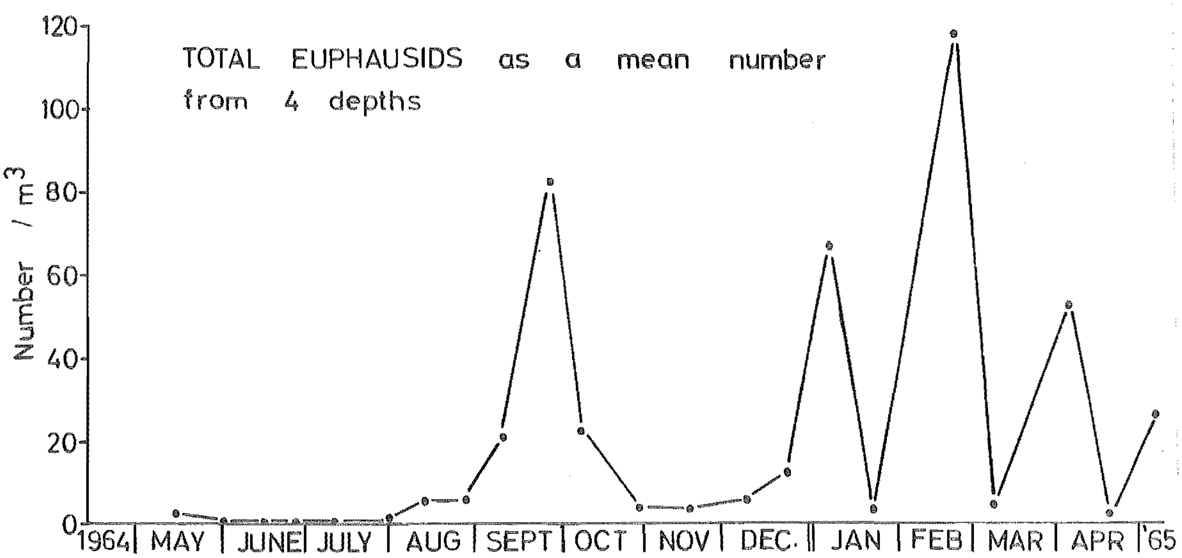


Fig. 33: Seasonal Cycle of Total Euphausiacea numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station", 1964-65

Fig. 32 shows the total numbers of Amphipoda/m^3. The maximum number found in August, September and December were mainly juveniles of the coastal species *Parathemisto australis*. The greatest concentration of Amphipoda was found most often at or just below the surface; these were mainly juveniles. Bonsfield (1951) suggested that the young stages were dependent on the phytoplankton for food, so the presence of large concentrations of juveniles at that surface is explained. Bary (1959) also recorded that *P. gracilis* and *P. australis* were consistently present at the surface in the daylight. On the other hand, adult Amphipoda are carnivorous. Hardy and Gunther (1935) reported that *Parathemisto gaudichaudii* fed mostly on young Euphausiacea, while Bonsfield recorded that *Themisto* sp. fed on Copepoda and other planktonic forms and was even cannibalistic. Representative samples of adult Amphipoda were probably not obtained, since they are very efficient swimmers. Amphipoda sometimes swarm and then become important as food for sea birds and fish as they did on 18 April '65.

Euphausiacea

The main species of Euphausiacea present, with their seasonal occurrence, are shown in the following table:

'64	A	M	J	J	A	S	O	N	D /	J	F	M	A	M '65
Nyctiphanes australis Sars, 1885	x			x			x	x	x	x				x
Euphausia lucens Hansen, 1905		x	x		x	x	x	x	x	x	x	x	x	x
Euphausia similis Sars, 1883					x	x			x	x				
Euphausia vallentini Stebbing, 1900			x		x									
Thysanoessa gregaria Sars, 1883		x	x		x			x	x	x	x		x	x
Nematoscelis megalops? Sars, 1883		x	x		x		x		x			x		

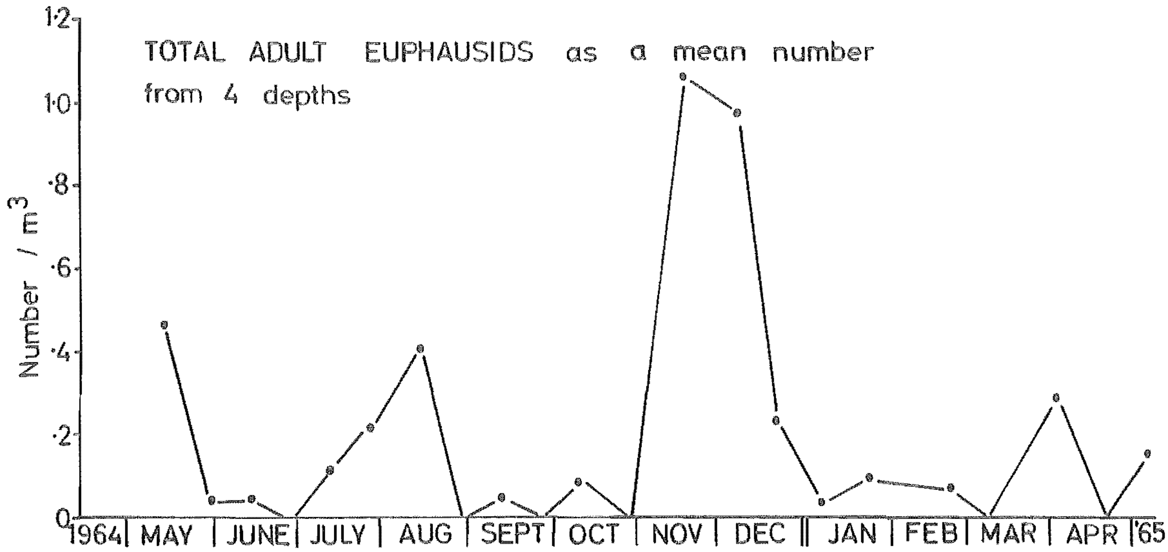


Fig. 34: Seasonal Cycle of Adult Euphausiacea numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

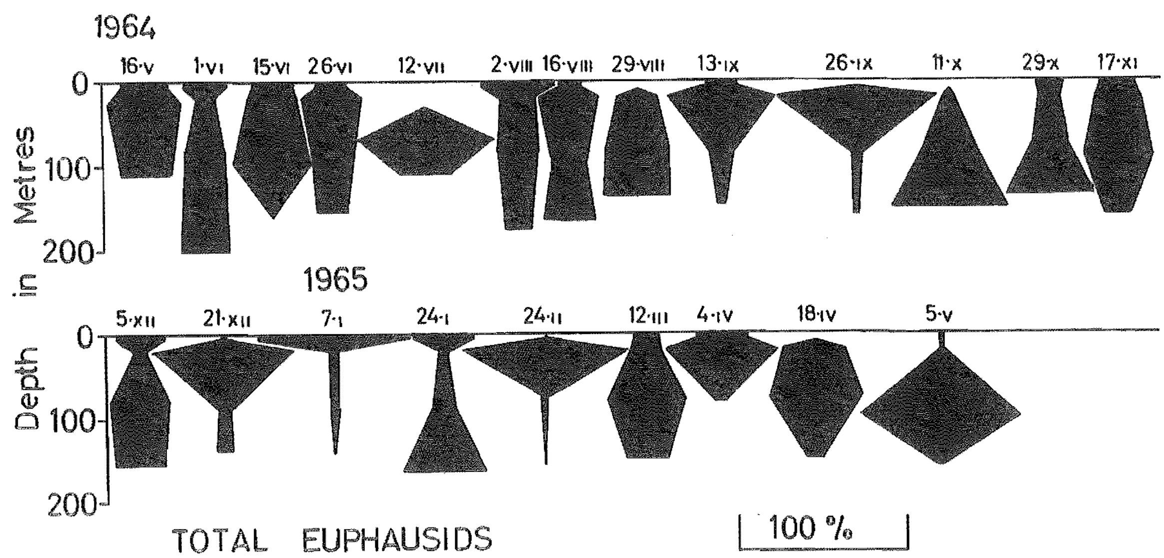


Fig. 35: Distribution of Total Euphausids with depth at the Kaikoura "Permanent Station"

As in the Copepoda, the total numbers of Euphausiacea fluctuated over short periods. The peak concentrations, seen in Fig. 33, were entirely due to calytopis and furcilia larvae. The adult Euphausiacea represented only a small proportion of the total numbers and peaks in their numbers did not correspond with the peaks in the total numbers (Fig. 34). The low total Euphausiacea numbers encountered during the period from May to August '64 may be accounted for when the contribution of stages in the life cycle of N. australis females is considered. Although Sheard (1953) (based on aggregated information from latitude 31-43°S) found ovigerous N. australis females during all months of the year except May and June, nauplii were absent from February to June. He found other larval stages of N. australis all year round.

The decrease in adult N. australis numbers at the end of December and January and their disappearance from samples in February, March and April was associated with an almost complete disappearance of shoals of Kahawai, Arripis trutta, from the beginning of January until the end of March '65. As well as a reduction in numbers of N. australis it may be seen in Fig. 34 that towards the end of December all adult species of the Euphausiacea were reduced in numbers until April '65. Kahawai depend for a great part of their diet in the Kaikoura region on N. australis, Munida gregaria and small fish amongst which are Pilchards, Sardinops neopilchardus, and Sprats, Maugeclupea antipodum (Graham, 1953). These latter small fish, in their turn, depend for food upon smaller planktonic organisms which were reduced in quantity during January, February and March '65 at Kaikoura (Fig. 21).

The maximum concentration of all stages of the Euphausiacea was found between 22 and 100m depth and on all but four occasions they were found at the surface (Fig. 35). According to Sheard (1953) the Euphausiacea, apart from the brief periods of surface swarming by neritic species, are inhabitants of the detritus-bearing water layers near the

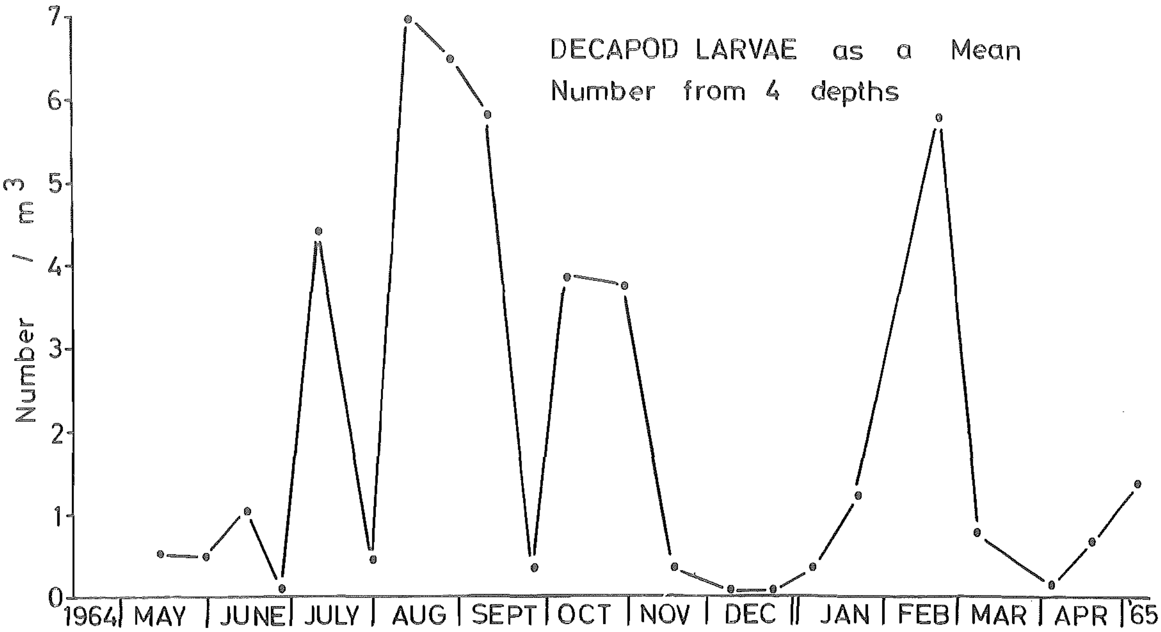


Fig. 36: Seasonal Cycle of Decapod Larvae numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

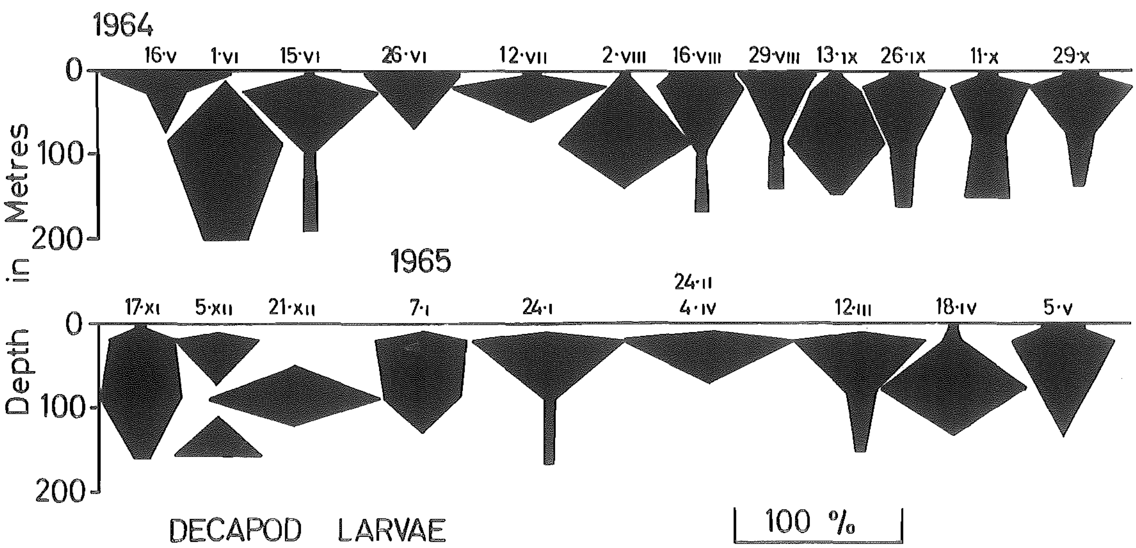


Fig. 37: Distribution of Decapod Larvae with Depth at the Kaikoura "Permanent Station"

bottom over the continental shelf. He gives evidence that the Euphausiacea have their main concentration below the Copepoda and feed extensively on Copepod faecal pellets as well as on live diatoms. From a comparison of Figs 35 and 30 it may be seen that the main concentration of Euphausiacea was below that of the Copepoda during the course of this study at Kaikoura. The swarming habit of N. australis for breeding purposes is well developed and many species of birds and fish depended on this at Kaikoura.

It has already been shown above that the Euphausiacea depend on the Copepoda to a large extent for their food. Also, an hypothesis has been put forward that the biomass of the general plankton, which is mainly Copepoda, was influenced to decrease by the disturbed hydrological situation during January, February and March '65. Thus the absence of adult Euphausiacea in general, during this same period, (Fig. 34) is explained, while in particular, the neritic N. australis would have been directly effected by the invasion of oceanic water. Juvenile Euphausiacean stages did not appear to have been effected to the same extent (Fig. 33) although they were subject to violent fluctuations in numbers during January, February and March '65.

Decapoda Larvae

Individual species have not been separated for the purposes of this study, except Munida sp. which will be discussed later.

Fig. 36 shows that larval Decapoda numbers began to increase in July with the bloom of Dinoflagallates Ceratium sp. There were great fluctuations in the numbers recorded. This was probably due to the appearance and disappearance of different species in the plankton. The greatest concentration was most often found at 22m depth (Fig. 37).

The larvae of all Galatheidea were removed from the

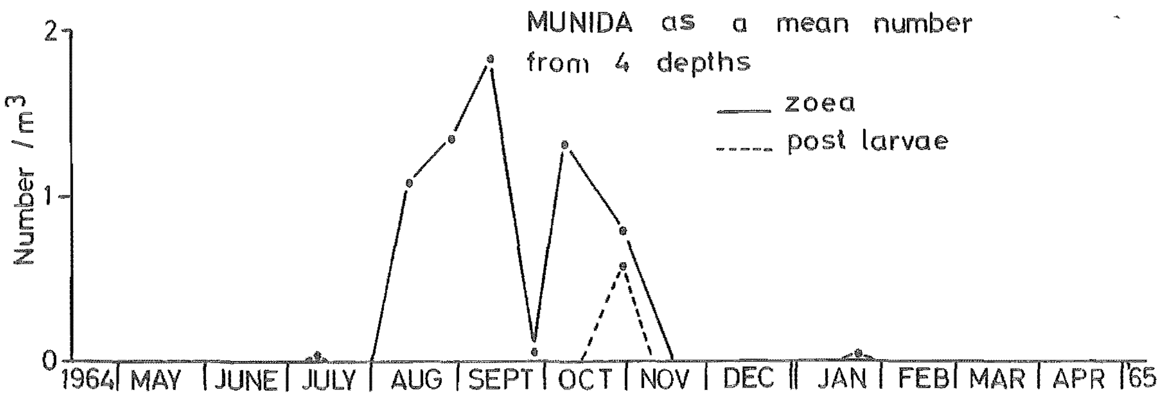


Fig. 38: Seasonal Cycle of Munida numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

samples. It was apparent that species of Galatheidae and Paguridae were present. Paguridae species were present from 16 August '64 until 24 February '65 with an occasional one appearing during the remainder of the sampling period. The Galatheidae fraction consisted of two _Munida_ species and one other species whose stage III, IV and V larvae were very like _Munida_ but the telson of the stage I and II larvae were not of the typical Munida form.

One of the _Munida_ species was rare as it was captured only on the following dates:

Stage I	29 August '64
Stage II	13 and 26 September '64 and 24 January '65
Stage III	7 January '65

This larva is similar to the one recorded by Gurney (1924). The remaining _Munida_ species belong to the _Munida subrugosa/ gregaria_ complex. In the Kaikoura samples zoeae were found from August to November '64 with a few occurring in July '64 and January '65 (Fig. 38). The only catch of post-larvae was taken in October.

There is considerable mystery about the connection between the adult _M. subrugosa_, which is bottom living, and the pelagic _M. gregaria_ as they produce identical larvae and are themselves similar except for slight differences in body proportions. It has been suggested by Rayner (1953) that _M. gregaria_ is the larva of _M. subrugosa_ which has failed to settle on the bottom, has become sexually mature and retained its larval body proportions.

Munida gregaria post-larvae are an important source of food for Kahawai (_Arripis trutta_) and have been found in the stomachs of Red Cod (_Physiculus bachus_). Large adult _M. gregaria_ were also found in the stomachs of Tunny caught off Doubtful Sound in February 1964. As _M. gregaria_ is an important source of food for pelagic fish it seems that a knowledge of the factors making the pelagic habit preferable

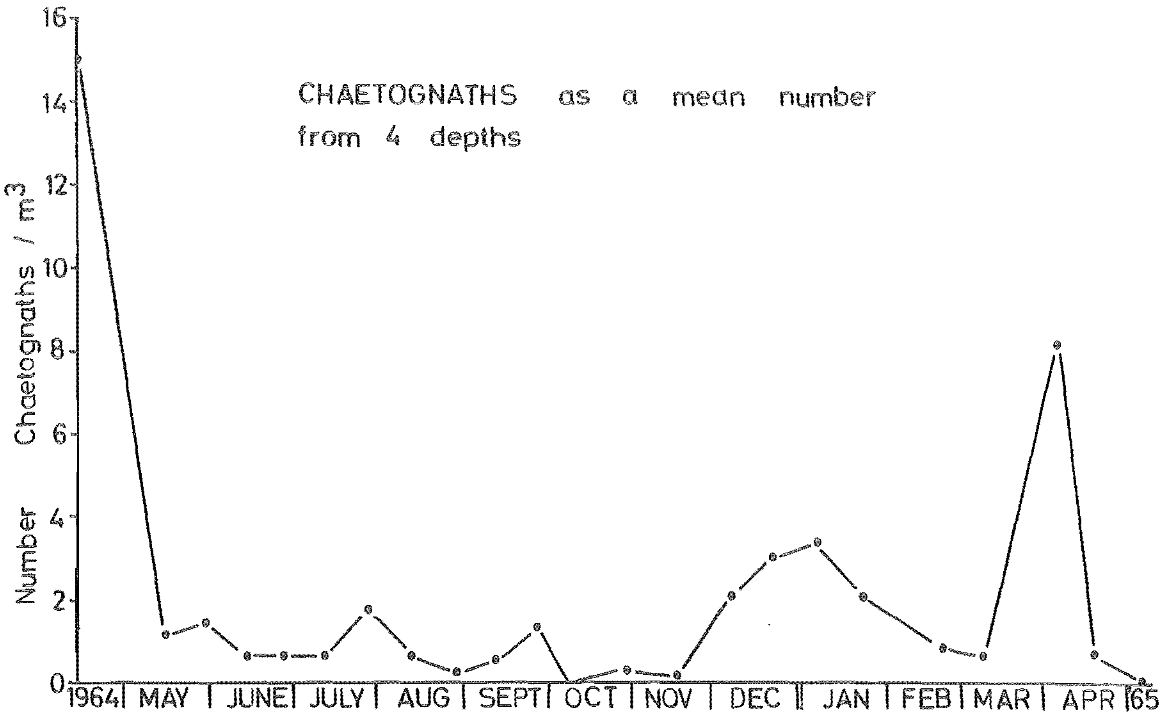


Fig.39: Seasonal Cycle of Chaetognatha numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

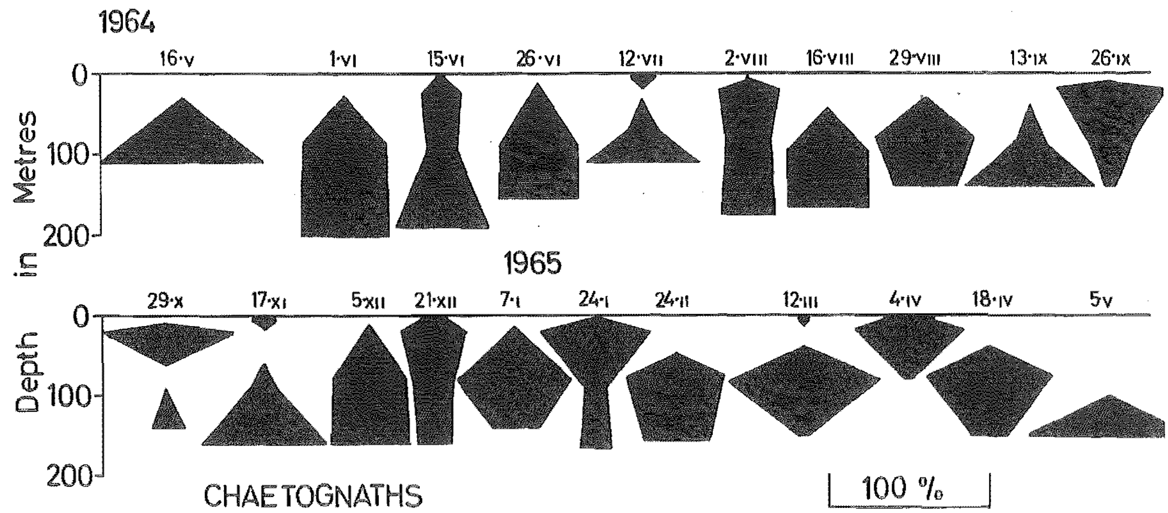


Fig. 40: Distribution of Chaetognatha with Depth at the Kaikoura "Permanent Station"

to *M. gregaria* would be very illuminating.

Chaetognatha

The most abundant amongst the species of Chaetognatha found at the "Permanent Station" was *Sagitta serratondentata*, Krohn, 1853, var. *tasmanica*, Thomson, 1947, which appeared all year round. *Sagitta gazellae*, Ritter-Zahony, 1909, appeared in considerable numbers from November to January '65 while an odd one or two appeared at other occasions (Fig. 57). It is probable that at least one other *Sagitta* species was present but because of the damaged lateral fins was not identified.

The greatest numbers of Chaetognatha were found during summer and autumn (Fig. 39). This agrees with the observations of Dakin and Colefax (1940) who found *Sagitta* sp. to be "most abundant in late summer and in autumn".

The greatest concentrations of Chaetognatha were most often found below 100m but never at the surface (Fig. 40). This ties in with their carnivorous habit. They have been observed with Copepoda, Euphausiacea, larval fish and other Chaetognatha in their guts (Hyman, 1959). She also recorded that they feed mainly at night or in dim light.

Larvacea

Different species were not separated for the purposes of this study. Bary (1960) identified *Oikopleura fusiformis* and *O. dioica* so it is probable that at least these 2 species were present.

The Larvacea were most abundant in August and September '64 and March '65 (Fig. 41) while their appearance at the surface seemed to be connected to some extent with their peak mean numbers. They were found in maximum concentration equally at all depths sampled (Fig. 42).

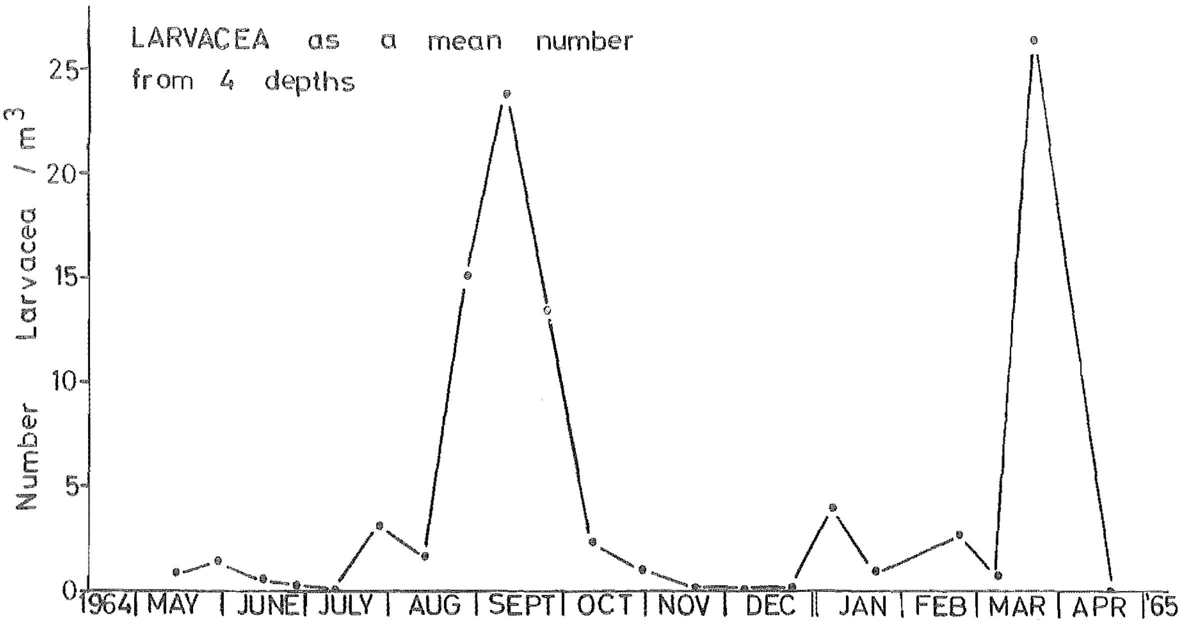


Fig. 41: Seasonal Cycle of Larvacea numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

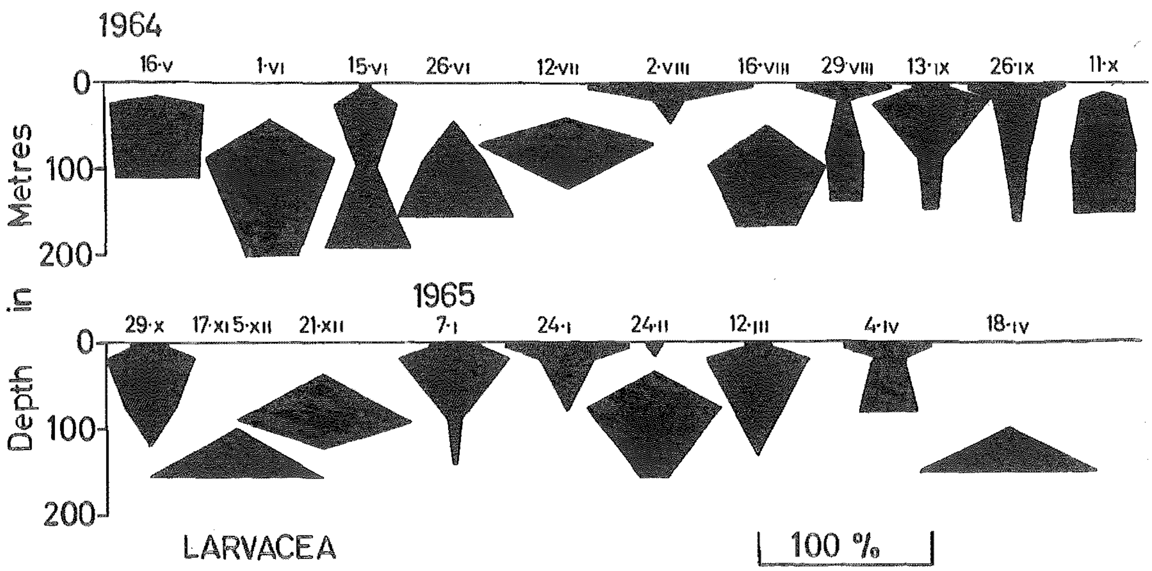


Fig. 42: Distribution of Larvacea with depth at the Kaikoura "Permanent Station"

Pyrosomatidae

Pyrosoma sp. were captured during April, May, June, August and September '64 and April '65. Juvenile stages were present on 14 April, 16 May and 26 September '64. It is probable that the species recorded was Pyrosoma atlanticum (Peron, 1804) as the only other species recorded off New Zealand by Bary (1960) was P. spinosum represented by a single specimen from the vicinity of Kaikoura. Bary (1960) also found P. atlanticum in large numbers to the east of Stewart Island in January and February and off Dunedin during March.

Salpidae

The Salpidae found at the "Permanent Station" were:

	Apr.	May 1964	Jan.	Mar.	Apr. 1965
Ihlea magalhanica (Apstein, 1894)	x	x			x
Salpa thompsoni Foxton, 1961			x		
Iasis zonaria (Pallas, 1774)			x	x	
Thalia democratica (Forskal, 1775)			x		

Ihlea magalhanica was the Salp found in the largest numbers. This species occurred when the subtropical influence was waning, while the other 3 species appeared with the warmest water. Tranter made a similar observation, that is, that Salps reached swarm proportions more commonly in the region of the Subtropical Convergence.

Larval Fish

Different species were not separated for the purpose of this study. The largest numbers were found between August and October '64 (Fig. 43). This corresponded with the spring phytoplankton bloom (Fig. 16). The maximum concentration of larval fish was found most often at 22m (Fig. 44). This, with their time of peak abundance, would indicate that

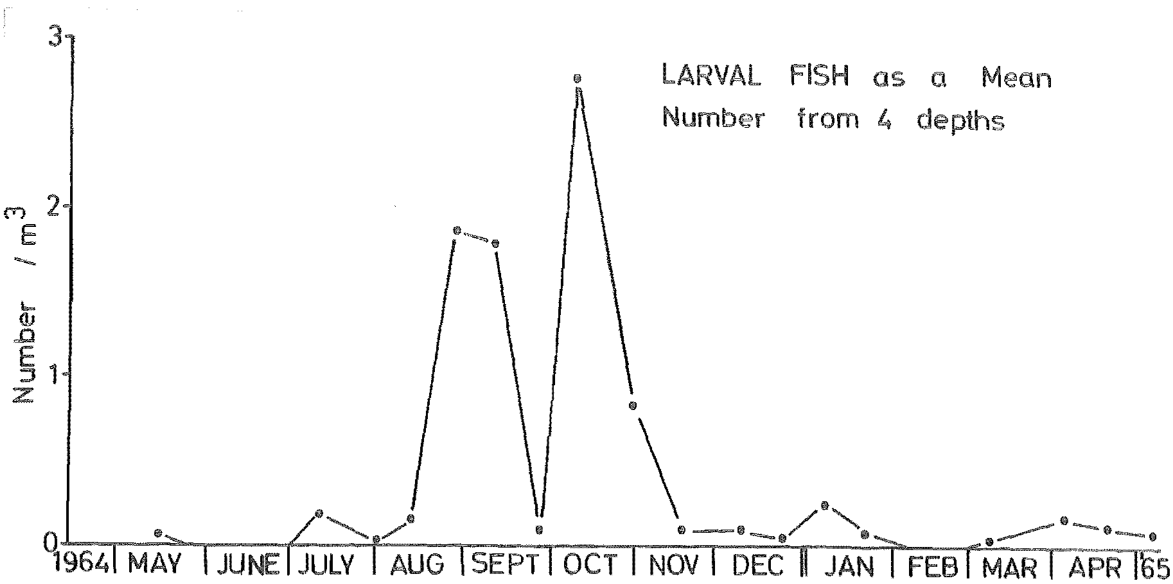


Fig. 43: Seasonal Cycle of Larval fish numbers/m^3 (as mean from four depths) at the Kaikoura "Permanent Station"

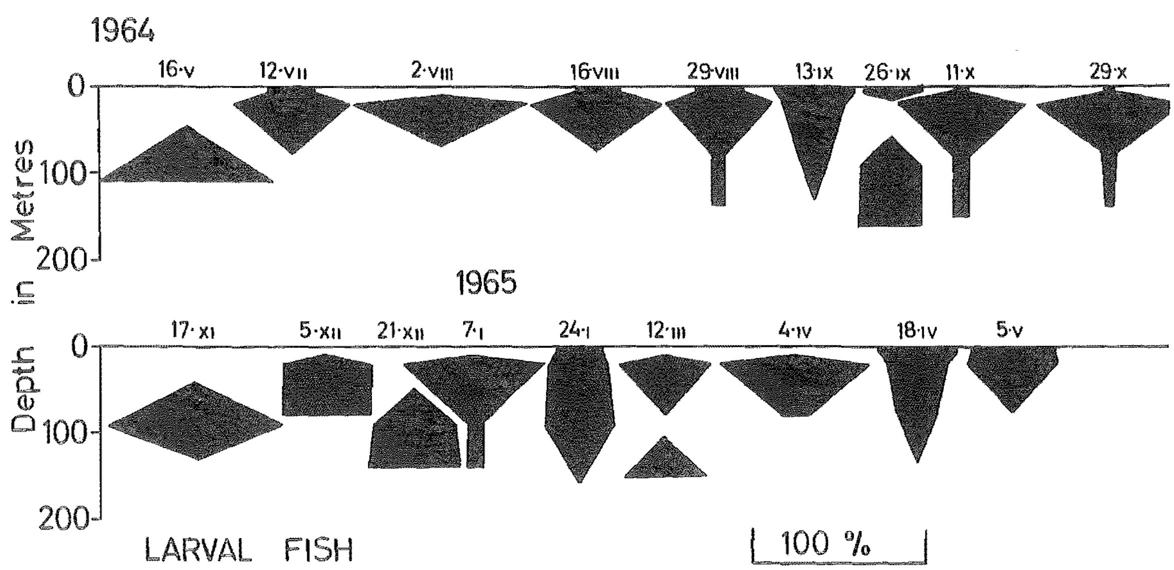


Fig. 44: Distribution of Larval fish with depth at the Kaikoura "Permanent Station"

most larval fish were feeding on the phytoplankton and small copepods.

DISCUSSION

During the course of this study no attempt was made to identify every species that occurred. Nevertheless it is possible to make generalisations about the zooplankton population as the most common species have been identified.

When the population, observed at the "Permanent Station" from 1964 to 1965, is compared with those populations recorded by Deevey (1952, 1956 and 1960) in Block Island Sound, Long Island Sound and Delaware Bay respectively (Riley et al, 1952, 1956; and Deevey, 1960), several important differences are noted. Deevey recorded Cladocera, many larval forms (Crustacean, Polychaete, Echinoderm and Molluscan), medusae and certain neritic genera of the Copepoda (*Eurytemora*, *Temora*, *Tortanus*, *Pseudodiaptomus*, and the Harpacticoid *Euterpina acutifrons*). In contrast Cladocera were not found at the "Permanent Station" while very few medusae and larval forms were recorded. Also none of the Copepod genera mentioned above were found at Kaikoura although *Temora turbinata* and *Euterpina acutifrons* were found to exist in the Bay of Island by Farran (1929). *Euterpina acutifrons* was also noted as occurring in a plankton sample collected by Dr Stonehouse from Port Underwood on 13 December '64. All these differences between the zooplankton population at the Kaikoura station and the populations described by Deevey are linked with the fact that Long Island and Block Island Sounds and Delaware Bay are enclosed bodies of water with low salinities.

The zooplankton population at the "Permanent Station" was composed of animals quoted on the left-hand side of Table 5. If the Kaikoura species, excluding those indicative of coastal influence, are considered, it will be seen that

Table 5: Comparison of Zooplankton Communities

Kaikoura Zooplankton Community	North Atlantic Calanus Community
Calanus australis	Calanus finmarchicus
Clausocalanus arcuicornis	Pseudocalanus
Clausocalanus sp.	
Metridia lucens	Metridia
Pleuromamma gracilis	
Euchaeta sp.	Euchaeta
Parathemisto sp.	Euthemisto
Euphausia lucens	Thysanoessa spp.
Sagitta serratodentata var. tasmanica (Low nos. in winter)	Sagitta serratodentata (absent in winter)
Coastal Additions	Possible Coastal Additions
Centropages aucklandicus	Centropages typicus
Oithona similis	Oithona similis
Acartia clausi	
Paracalanus parvus	
Nyctiphanes australis	Meganyctiphanes
Pleurobrachia pileus	Ctenophora
	Sagitta elegans

the population is somewhat similar to the Calanus community (right-hand side of Table 5) of the North Atlantic (Raymont, 1964 pp336-338). The genera of Copepoda are almost identical with one important difference: Pseudocalanus of the North Atlantic is replaced by at least two species of Clausocalanus at Kaikoura. Both of these genera belong to the Pseudocalanidae. The Copepod Euchaeta did not play an important role in the Kaikoura community although Metridia and Pleuromamma had approximately equal status.

Thus, although the "Permanent Station" was not truly an oceanic station and was under the influence of subtropical water to a greater or lesser extent during the year 1964-65, remarkable similarities are seen between the two above communities.

CONCLUSIONS

The zooplankton population at the "Permanent Station" showed similarities to a North Atlantic Calanus community.

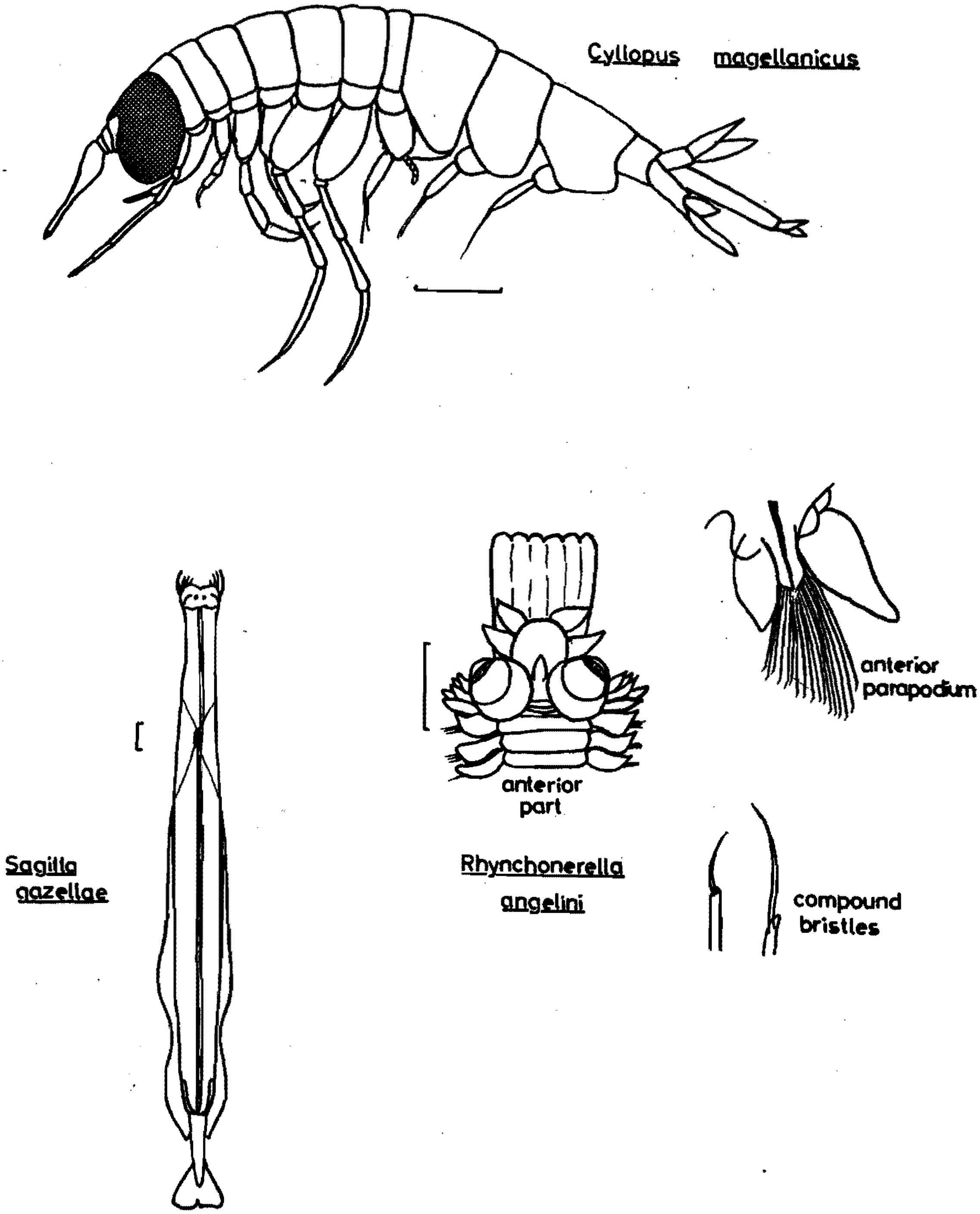
All planktonic groups of animals, except the predators (Ctenophora and Chaetognatha), tended to have their initial or main annual increase at the time of the spring phytoplankton bloom: that is, in August and September. The manner in which each group was most frequently distributed with depth was usually in agreement with the feeding habits of the group. Although deviations from these patterns were not frequent they were probably connected with aspects of the animals' biology and ecology: for example, movements for the purpose of breeding.

Several species were recorded that are known to be important as food for pelagic fish and sea birds. These species are the Euphausiacea, the Deopod Munida gregaria, the Amphipoda and the Copepod Calanus tonsus. It is doubtful whether the first three were adequately sampled as the nets used were not designed to capture the strong swimming macroplankton.

Amongst the Copepoda were two species which showed how little relationship numbers had to biomass. *Oithona* sp. which were often present in large numbers, never contributed a fraction of the amount that *Calanus tonsus* did to the biomass.

In general the cycle of mean numbers should have been influenced mainly by the biology of the species concerned, but it seemed that this was not always so. The numbers of Copepoda and Euphausiacea in particular seemed to be influenced by the hydrological situation, especially at the beginning of 1965.

FIG. 45


Cyllopus magellanicus
Sagilla gazellae
anterior part
Rhynchonerella angelini
anterior parapodium
compound bristles

E. THE ZOOPLANKTON AS INDICATORS OF WATER MOVEMENTS AT THE "PERMANENT STATION" OFF KAIKOURA

a) Systematic and Zoogeographic Notes on Species of Zooplankton found at the "Permanent Station" and Discussed in Section E (b)

1mm is marked on all drawings from Fig. 45 to Fig. 54.

Chaetognatha

Sagitta gazellae Ritter-Zahony, 1909 Fig. 45

This Chaetognath is distinguished from *S. lyra* by the expression of the width apart of the eyes as a percentage of the head width; this is always less than 30%.

Sagitta gazellae was found throughout the year at Kaikoura but the greatest numbers were captured during summer. A few specimens caught in August and September '64 had more than eleven hooks while not one individual was caught at a stage of maturity greater than stage III.

David (1955) has shown that this species is distributed over Antarctic and subantarctic waters and Bary (1959) grouped it with his Southern Subantarctic Group of species.

Polychaeta

Rynchonerella angelini (Kinberg, 1866) Fig. 45

This Polychaete was captured on 12 July (length 30mm) and 5 December (lengths 50 and 70mm). Tebble (1960) reported the distribution of *R. angelini* as being general over the Atlantic Ocean where its southern limit is probably at the Subtropical Convergence. The type locality of this species is the China Sea which appears to be the location nearest to New Zealand at which *R. angelini* has been recorded.

Amphipoda

Cyllopus magellanicus Dana, 1853 Fig. 45

This species was captured in April and May '64, January and April '65 at Kaikoura. There was some variation in the number of segments making up the fifth paraepod; that is, there were sometimes four segments besides the basos, not the usual five segments (Hurley, 1954). A number of large adult specimens were caught off the Kaikoura wharf on 2 February '65. Barnard (1930) recorded the occurrence of this species south of New Zealand while Bary (1959b) confirmed the subantarctic distribution of *C. magellanicus*.

Copepoda

Calanus tonsus Brady, 1883 Fig. 46

This Copepod was recognised as being similar to the *Calanus tonsus* figured and described by Vervoort (1957) although the spines on the 2nd basipods of the 2nd to 5th swimming legs seemed somewhat variable; also, he did not figure the recurved spine on the 2nd exopod segment of the 2nd swimming legs. The Kaikoura specimens appear similar to those described by Bary (1951) as *Neocalanus tonsus*. He recognises this species as *Calanus tonsus* described by Brady and recorded by Farran (1929) but he thinks it should be within the genus *Neocalanus* on the basis of:

(i) a recurved spine on the 2nd exopodal segment of the 2nd legs,

(ii) the seta formula of the 1st maxillipede,

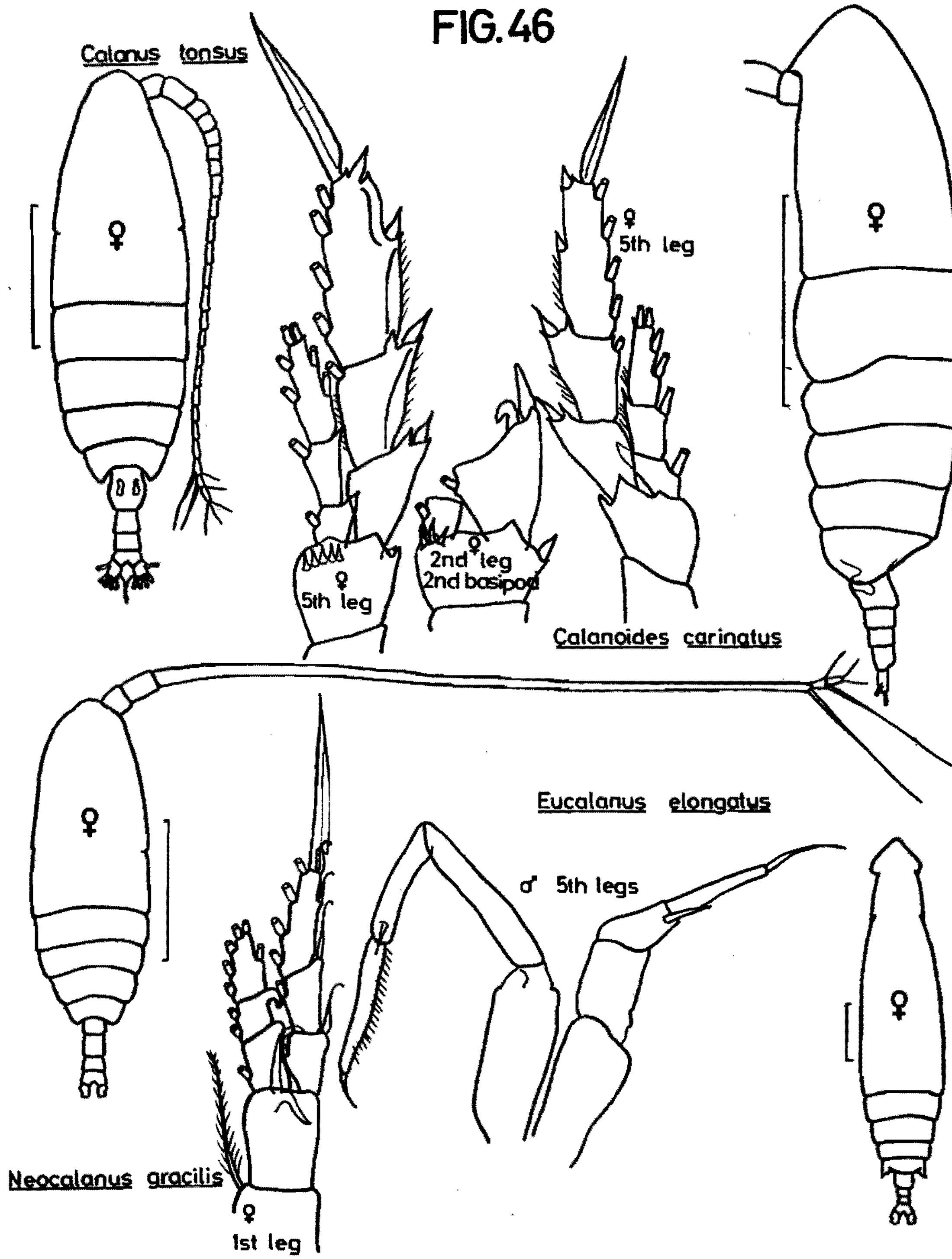
(iii) the "shoulder" on the outer distal margin of the 1st basipod of the 1st maxillipede,

(iv) the structure of the 1st foot,

(v) and the number and disposition of the setae on the inner rami of the 1st to 5th feet.

Calanus tonsus was captured in spring, as females and stage V copepodites, and during summer, as huge numbers of

FIG. 46



Calanus tonsus
♀
♀
5th leg
♀
2nd leg
2nd basipod
♀
5th leg
♀
Calanoides carinatus
♀
Eucalanus elongatus
♂ 5th legs
♀
Neocalanus gracilis
♀
1st leg

stage V copepodites almost exclusively. Vervoort (1957) described C. tonsus as occurring over the whole of the Pacific Ocean and as being particularly characteristic of subantarctic epiplankton. He also recorded that C. tonsus was very abundant south of Australia while Farran (1929) noted the capture of appreciable numbers of this species in the north of the New Zealand region. Bary (1951) captured a few specimens of this species in Cook Strait during January but found they were plentiful to the south of New Zealand. His most prolific hauls were made in coastal waters which led him to use N. tonsus as an indicator of coastal water although he noted its disappearance when subantarctic influence was strong. At the Kaikoura "Permanent Station" the appearance of this same species coincided with the introduction of warm oceanic water.

There is obviously much mystery about the factors limiting this species (if indeed it is one). There is some suggestion that in near-shore waters it is able to reproduce prolifically and that this population is sensitive to different limiting factors when compared with the oceanic populations.

Calanoides carinatus (Kroyer, 1849) Fig. 46

This species was captured at Kaikoura during spring and summer, usually in conjunction with Calanus tonsus. Vervoort (1957) described the geographical distribution of C. carinatus as covering a vast part of the tropical and subtropical Indo-west Pacific and Atlantic Oceans and recorded its capture to the south of Tasmania. Bary (1951) found this species to be common in Cook Strait in January and off the east coast of the South Island from January to March, but it was not taken in the subantarctic or away from immediately coastal waters. This is also in direct contrast to the fact that C. carinatus was captured at the Kaikoura station during this study only when the water became warm and of more oceanic character.

Neocalanus gracilis (Dana, 1849) Fig. 46

This rare species was captured at Kaikoura in April and June. Bary (1951) captured this species between Cook Strait and the south-east area of New Zealand where it was uncommon but it was not taken south of New Zealand. Vervoort (1957) summarised the geographical distribution of N. gracilis as being over the tropical, subtropical and temperate zones of the Atlantic and Indo-west Pacific. He recorded the capture of N. gracilis to the south of Tasmania while Farran (1929) recorded it from the northern New Zealand region.

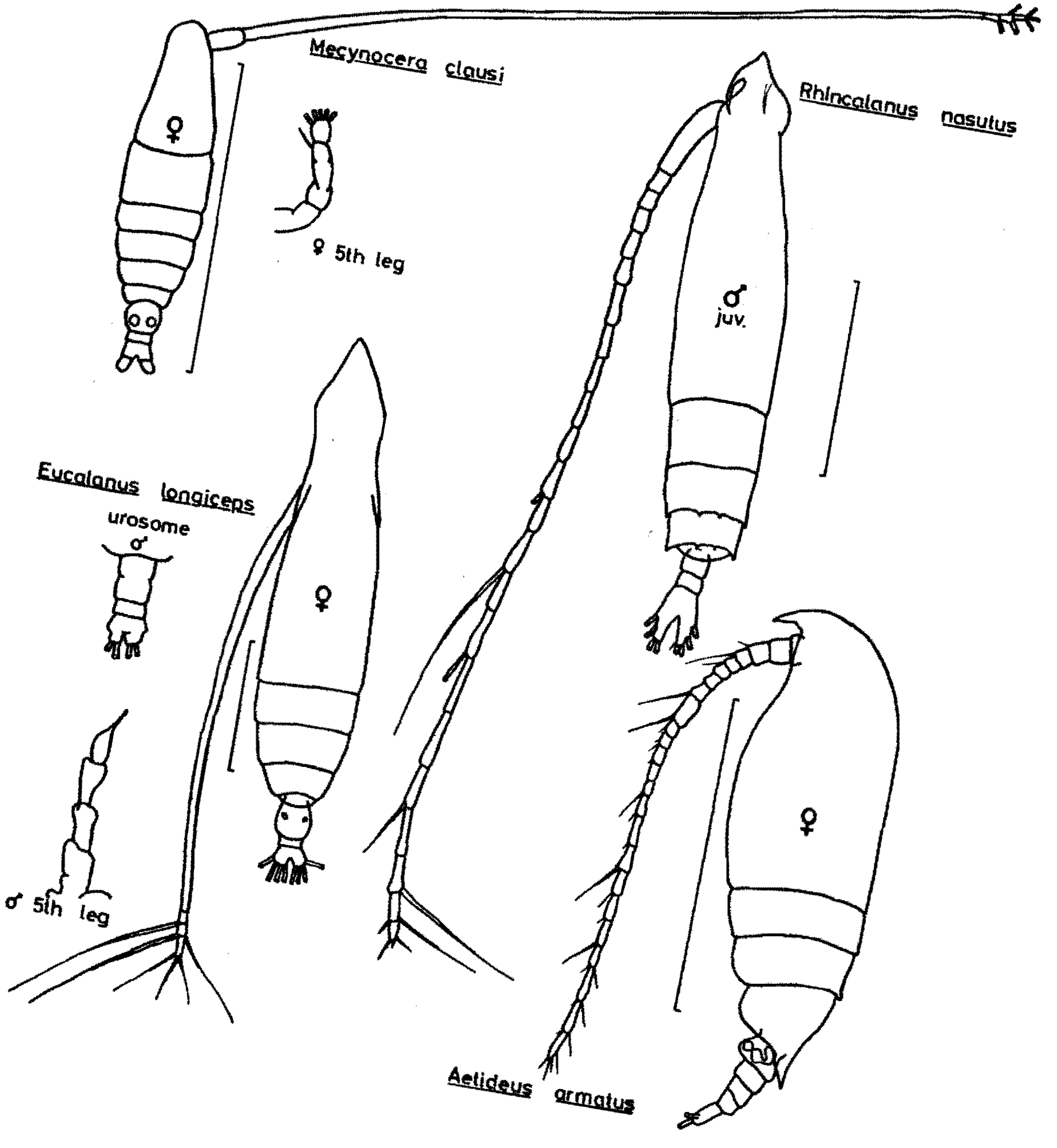
Eucalanus elongatus (Dana, 1849) Fig. 46

This species was captured at Kaikoura in April, September, October and November '64, January, March and April '65. No more than two specimens of this large copepod were taken at any one time. Bary (1951) captured this oceanic species to the south-east of New Zealand, Farran (1929) found E. elongatus at many stations south of New Zealand and Vervoort (1957) recorded this species as originating from intermediate depths although Farran captured it at the surface on several occasions.

Eucalanus longiceps Matthews, 1925 Fig. 47

This species was captured in all months of the year except May, August and December '64 and May '65; it was generally more plentiful than E. elongatus. Bary (1959a) used E. longiceps under the synonym of E. acus to indicate southern subantarctic water, citing as evidence the fact that Farran recorded this animal frequently from the south of New Zealand. When E. longiceps was captured during summer at Kaikoura it was never at the surface in the warmest water. Vervoort (1957) has summarised the scattered distribution of E. longiceps.

FIG. 47


Mecynocera clausi
♀
♀ 5th leg
Rhincalanus nasutus
♂
juv.
Eucalanus longiceps
urosome
♂
♀
♂ 5th leg
♀
Aetideus armatus

Rhincalanus nasutus Giesbrecht, 1888 Fig. 47

This species was captured on one occasion during June at Kaikoura. Bary (1951) captured R. nasutus south of New Zealand and north-east of Dunedin during March, while Farran (1929) reported it from samples taken in the northern New Zealand region. Rhincalanus nasutus seems to be common in subantarctic waters although it is certainly of subtropical origin (Vervoort, 1957).

Mecynocera clausi I. C. Thompson, 1888 Fig. 47

This species was captured only during May, June and December '64 at Kaikoura. Bary (1951) caught M. clausi occasionally in the area between Stewart Island and just north of Banks Peninsula, while Farran (1929) recorded it at many stations in the northern New Zealand region and at two stations east of New Zealand. Mecynocera clausi has a wide range of distribution in tropical, subtropical and temperate waters (Vervoort, 1957).

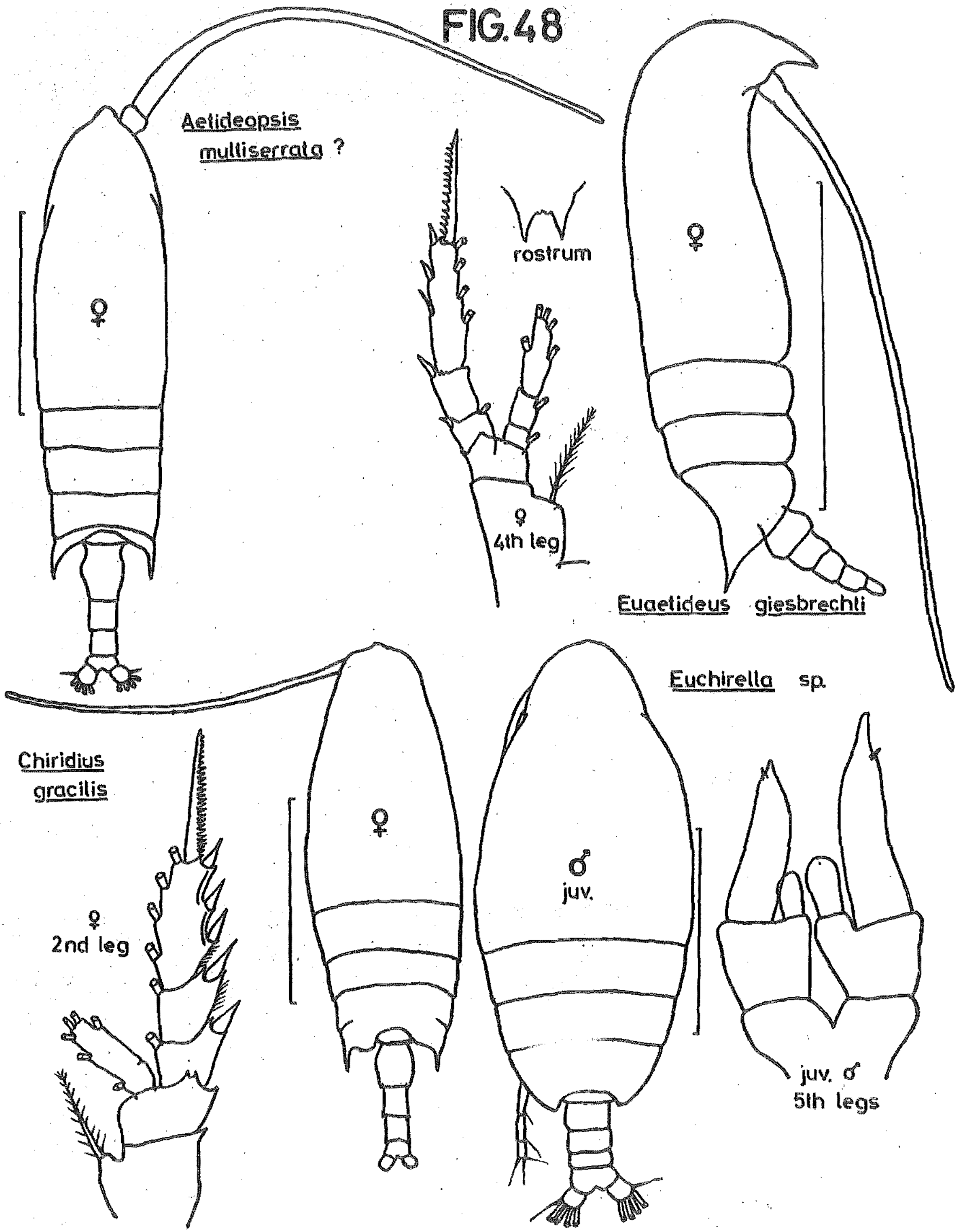
Aetideus armatus (Boeck, 1872) Fig. 47

This species was captured in April and September '64, and January, February and April '65 at Kaikoura. No more than a few specimens were taken at one time. Bary (1951) captured A. armatus south of New Zealand in November and off Banks Peninsula and Dunedin during March. Aetideus armatus is probably a southern species although Farran (1929) recorded two specimens in the region north of New Zealand. Vervoort (1957) recorded that this species appears to prefer mid-water layers as the individuals he captured south of Tasmania were below 100m depth. The geographical distribution of A. armatus is wide but it seldom occurs in large numbers (Vervoort, 1957).

Euaetideus giesbrechti (Cleve, 1904) Fig. 48

One specimen of this species was captured in April '64 at Kaikoura. It differed from the specimen figured by

FIG.48


Aetideopsis multiserrata ?
♀
rostrum
♀ 4th leg
♀
Euaetideus giesbrechti
Euchirella sp.
Chiridius gracilis
♀ 2nd leg
♀
♂ juv.
juv. ♂ 5th legs

Vervoort (1957) as a row of small spines were present at the base of the seta on the 1st basipod of the 4th swimming legs. Vervoort (1957) summarises the geographical distribution of E. giesbrechti as the Indo-Pacific East Pacific and Atlantic region. He also shows that it usually occurs between 200-350 metres' depth, whereas Farran (1929) captured it in superficial water layers to the north of the New Zealand region where it was probably carried by upwelling water.

Aetideopsis multiserrata (Wolfenden, 1904) Fig. 48

Specimens were captured during October '64 and April '65 which were provisionally identified as A. multiserrata; the bulbous shape of the genital segment, viewed dorsally, differs from Rose's (1933) figure and the posterior corners of the 5th thoracic segment pass the middle of the genital segment. Rose recorded the distribution of this species as being the Atlantic and the Malay Archipelago. This present record may be the first of this species in the New Zealand region.

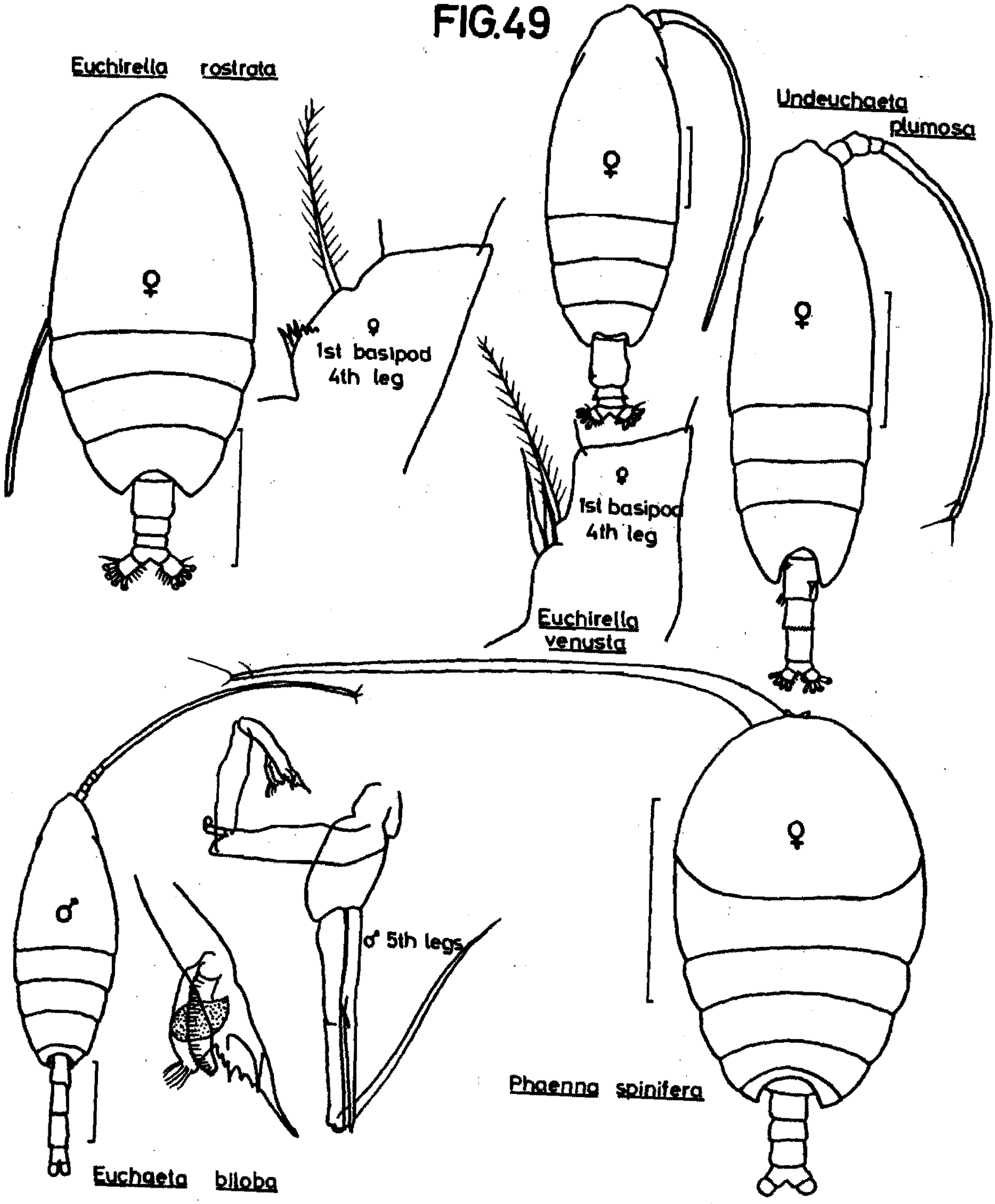
Chiridius gracilis Farran, 1908 Fig. 48

This species was captured once at the beginning of June '64 at Kaikoura. Farran (1929) noted this species from the north of the New Zealand region while Vervoort (1957) recorded one specimen captured south of Tasmania. Vervoort (1957) summarised the distribution of C. gracilis as being the Indo-west Pacific and Atlantic regions where it is found sparingly.

Euchirella venusta Giesbrecht, 1888 Fig. 49

This species was distinguished from E. pulchra and E. orientalis, which also have the same number of spines on the 1st basipod of the 4th swimming legs, by the number of setae on the two lobes of the terminal endopod segment of the 2nd antenna; Euchirella venusta bears 5 and 4 setae on each lobe respectively (Sewell, 1929). The urosome of the Kaikoura specimens differs from Vervoort's (1952) figure as

FIG.49


Euchirella rostrata
♀
♀
1st basipod
4th leg
♀
Undeuchaeta plumosa
♀
♀
1st basipod
4th leg
Euchirella venusta
♂
♂ 5th legs
Euchaeta biloba
♀
Phaenna spinifera

the posterio-lateral borders of the 2nd urosome segment are ornamented with small spines (Fig. 49). This large (5·1mm) species was captured on one occasion in January '65 at Kaikoura. Farran (1929) recorded eleven specimens of E. venusta from the north of the New Zealand region while Vervoort (1952) described this species as being of Pacific origins.

Euchirella rostrata (Claus, 1866) Fig. 49

This species was captured during December '64 on two occasions at Kaikoura. The length of the female caught on 21 December was 3·7mm; this is slightly bigger than the maximum of 3·4mm recorded by Farran (1929). Farran recorded E. rostrata many times from the north of the New Zealand region and Vervoort (1957) found it south of Tasmania. Vervoort (1957) described it as a species with a wide area of distribution which extends over the tropical, subtropical and temperate regions of the Atlantic, Pacific and Indian Oceans.

Euchirella sp. Fig. 48

Juvenile males of the genus Euchirella were captured at Kaikoura on September '64. They were 2·7mm in length.

Undeuchaeta plumosa (Lubbock, 1856) Fig. 49

This species was captured during January '65 at Kaikoura. It has been previously found by Bary (1951) in Cook Strait during March; it was noted by Farran (1929) as numerous specimens from the north of the New Zealand region and Vervoort recorded one male from south of Tasmania. Vervoort (1957) discussed the geographical distribution which is in general the Indo-west Pacific, the east Pacific and the Atlantic Ocean from 63°N to 53°S. U. plumosa is found mainly in moderately deep waters (Vervoort, 1957) but may be captured at the surface (Farran, 1929).

Euchaeta biloba (Farran, 1929) Fig. 49

One male specimen was captured in June '64 at Kaikoura. Farran recorded this species south of New Zealand while Vervoort (1957) noted its capture south of Tasmania. Euchaeta biloba is of subantarctic origin, is present in surface and intermediate water masses and occasionally penetrates waters south of the polar circle (Vervoort, 1957).

Euchaeta sp.

Juveniles of this genus were captured in September at Kaikoura.

Phaenna spinifera Claus, 1863 Fig. 49

One female specimen of this species was captured at Kaikoura in April '65. Farran (1929) recorded three individuals of P. spinifera off the north of New Zealand. Rose (1933) recorded this species as occurring in the Pacific, Indian and Atlantic Oceans and also in the Mediterranean.

Metridia lucens Boeck, 1864 Fig. 50

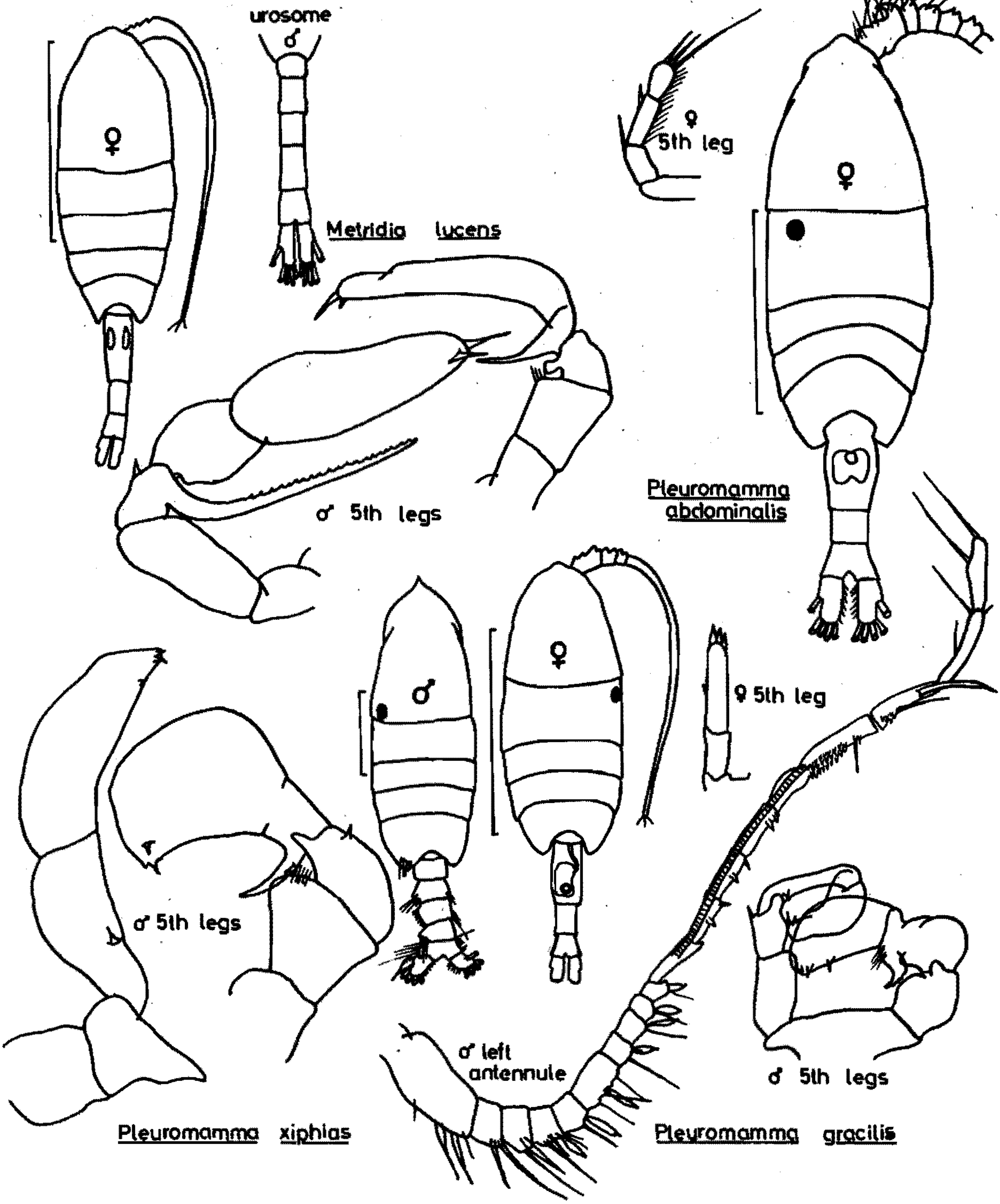
This species was captured in all months sampled at Kaikoura except February and March '65.* Farran (1929) recorded M. lucens south of New Zealand from 52° 11'S while Vervoort found that it occurred exclusively in intermediate and deeper waters at B.A.N.Z.A.R.E. stations, particularly south of Tasmania. Vervoort (1957) stated that the distribution of M. lucens is almost world-wide.

*Bary (1951) found M. lucens to be a moderately common Copepod from east of Kaikoura to the south of New Zealand.

Pleuromamma abdominalis (Lubbock, 1856) Fig. 50

This species was captured at Kaikoura during April, May, June and August '64 and January '65. No males were found. Previous records from the New Zealand region are to be found in Bary (1951) who captured P. abdominalis east of Kaikoura

FIG. 50



urosome
♂
♀
Metridia lucens
♀
5th leg
♀
♂ 5th legs
Pleuromamma abdominalis
♂
♀
♀ 5th leg
♂ 5th legs
♂ left antennule
♂ 5th legs
Pleuromamma xiphias
Pleuromamma gracilis

during March, in Farran (1929) who noted this same species to occur frequently to the north of New Zealand and in Vervoort (1957) who recorded it from south of Tasmania. Sewell (1932) recorded P. abdominalis as having an almost world-wide distribution covering the Pacific, Indian and Atlantic Oceans. Vervoort (1957) stated that no specimen has ever been found south of 60°S. Pleuromamma abdominalis was captured once during a horizontal haul on 24 January '65 at Kaikoura at a depth of 164m. This fact agrees with Sewell's (1932) opinion, that P. abdominalis usually lives at depths although it may be caught at the surface.

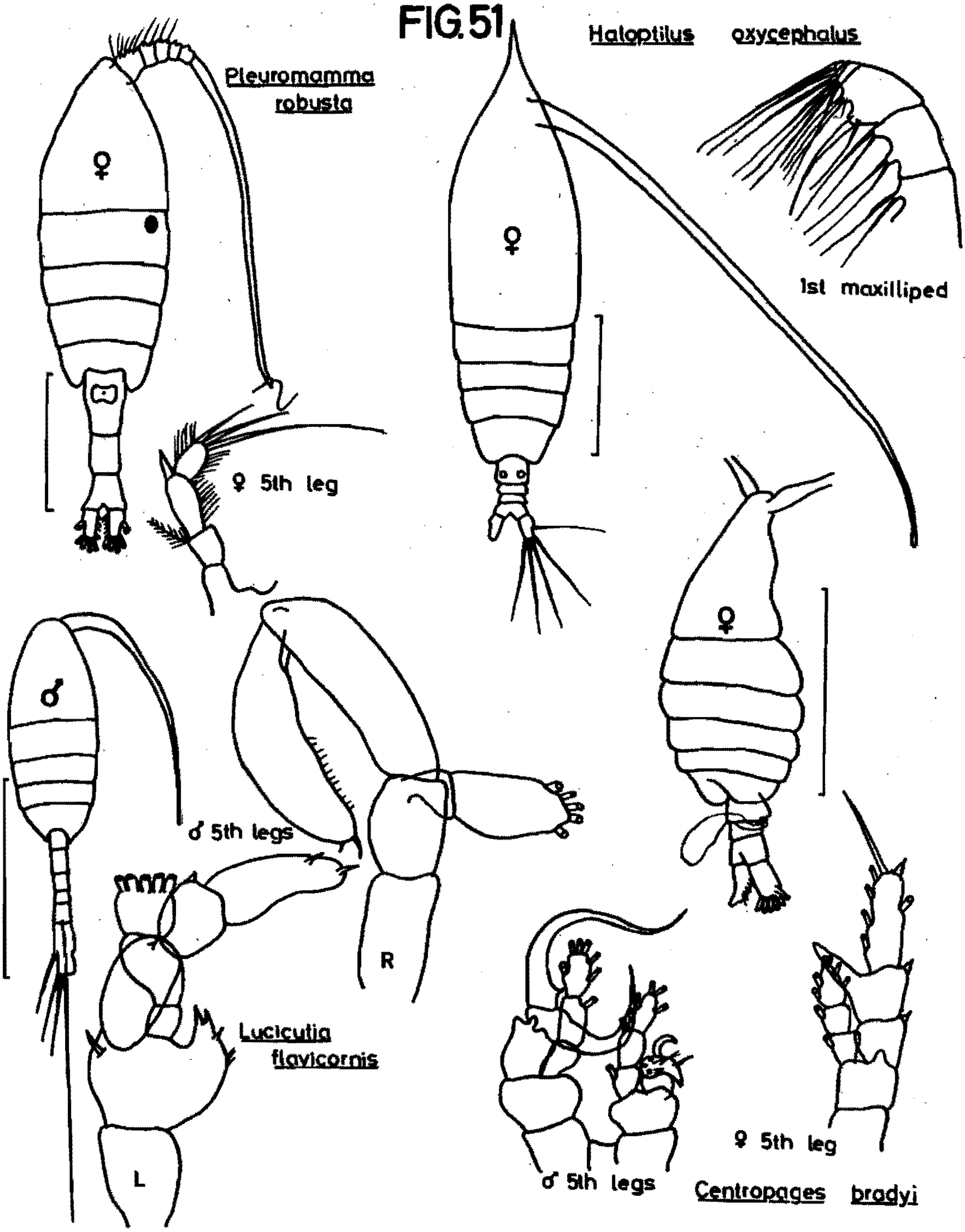
Pleuromamma xiphias (Giesbrecht, 1889) Fig. 50

One male specimen of P. xiphias was captured in January '65 at Kaikoura. Farran recorded this species occasionally from the north of the New Zealand region and once in large numbers at the surface at night. Vervoort (1957) noted that P. xiphias was present south of Tasmania and also recorded that it has a distribution which covers tropical, subtropical and temperate deep water regions of the Atlantic, Pacific and Indian Oceans.

Pleuromamma gracilis (Claus, 1863) Fig. 50

There were only two months when P. gracilis was not captured; July '64 and February '65. All specimens studied were definitely P. gracilis although Farran recorded that P. piseki Farran, 1929 had the same range as P. gracilis to the north of the New Zealand region; Vervoort recorded P. piseki south of Tasmania but made no reference to P. gracilis. Pleuromamma gracilis was taken by Bary (1951) off Kaikoura during March and it occurs frequently in the north temperate and tropical Atlantic and was common off New Zealand as far as the Auckland and Campbell Islands (Farran, 1929).

FIG.51



Haloptilus oxycephalus
Pleuromamma robusta
♀
1st maxilliped
♀
♀ 5th leg
♂
♀
♂ 5th legs
R
Lucicutia flavicornis
L
♀ 5th leg
♂ 5th legs
Centropages bradyi

Pleuromamma robusta (F. Dahl, 1893) Fig. 51

Pleuromamma robusta was captured at Kaikoura in June and August '64 and January '65. The Kaikoura specimens appear to be the scantily haired P. robusta forma antarctica Steuer, 1931. Vervoort (1957) recorded the capture of this form as far north as 45° 10'S in the Indian Ocean where it was always captured at depths greater than 250m. He interpreted the B.A.N.Z.A.R.E. data as showing that P. robusta forma antarctica is of subantarctic rather than antarctic distribution. Farran (1929) also recorded the capture of considerable numbers of this species south of New Zealand.

Centropages bradyi Wheeler, 1900 Fig. 51

This species was captured at Kaikoura in April, May and December '64. Centropages bradyi was previously recorded from the New Zealand region by Bary (1951) who captured it in the area between Stewart Island and Banks Peninsula from March onwards and in Cook Strait during March, by Farran (1929) in the north of the New Zealand region and by Vervoort who found three specimens south of Tasmania. Centropages bradyi is distributed over the whole tropical and temperate Atlantic, the east Pacific and the Indo-west Pacific (Vervoort, 1957).

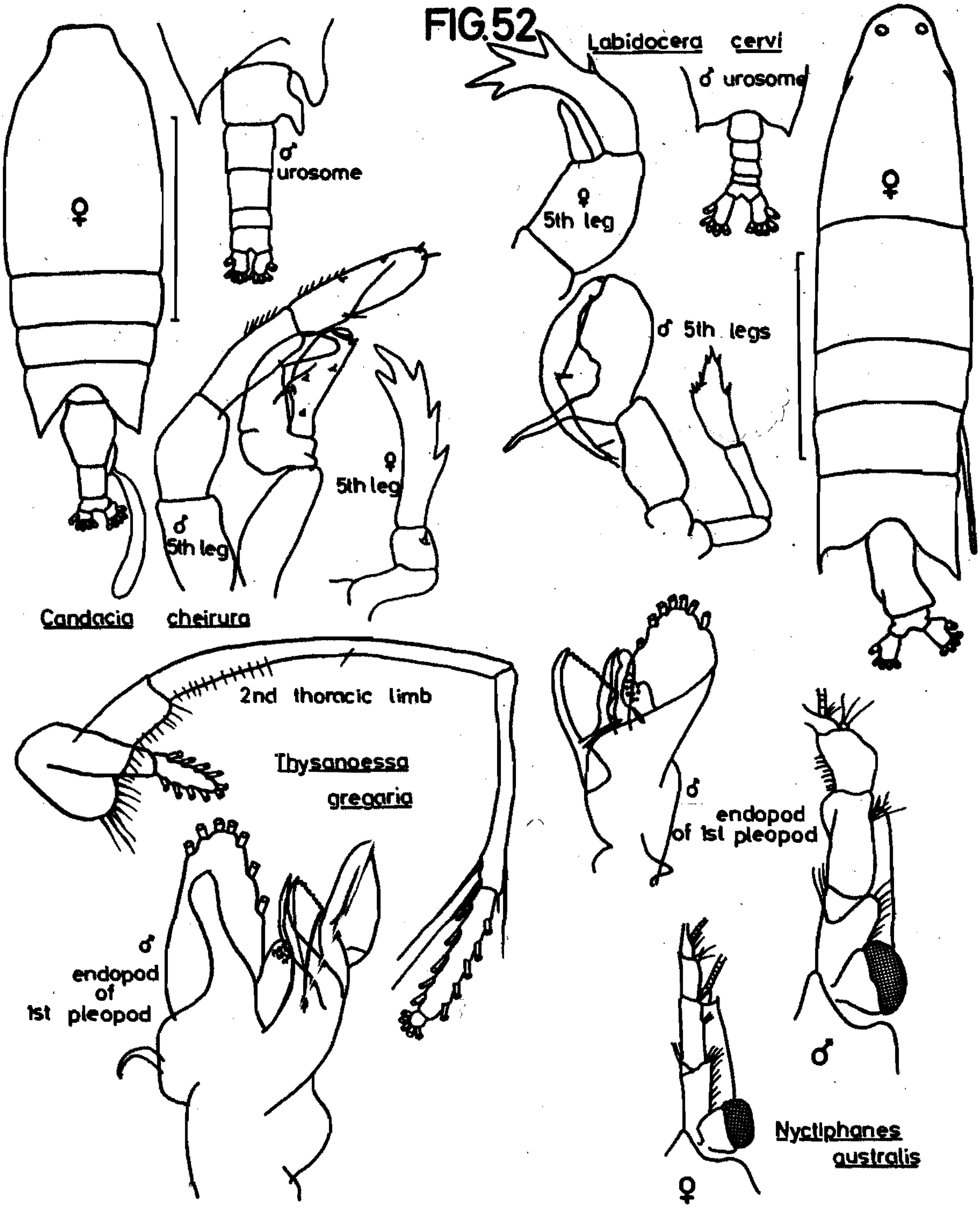
Lucicutia flavicornis (Claus, 1863) Fig. 51

This species was captured at Kaikoura during June and August '64 and January '65. Farran (1929) recorded L. flavicornis previously as being very common in the north of the New Zealand region.

Haloptilus oxycephalus (Giesbrecht, 1889) Fig. 51

Two female specimens of this species were captured at Kaikoura in January '65. Farran (1929) noted the occurrence of H. oxycephalus well to the south of New Zealand; Vervoort (1957) did not record it from the Australia-New Zealand

FIG.52



Labidocera cervi
♂ urosome
♀
♀ 5th leg
♂ 5th legs
♂ urosome
♀
♂ 5th leg
♀ 5th leg
Candacia cheirura
2nd thoracic limb
Thysanoessa gregaria
♂ endopod of 1st pleopod
♂ endopod of 1st pleopod
♂
Nyctiphanes australis
♀

region but he summarised its distribution which covers the antarctic, tropical and temperate parts of the Atlantic and Pacific Oceans and also the Mediterranean Sea. He stated that in tropical and temperate localities the species is decidedly a deep water form.

Candacia cheirura Cleve, 1904 Fig. 52

This species was captured at Kaikoura during April, May, June, August, September, November and December '64 and January '65. Candacia cheirura has been previously recorded by Bary (1951) who took it east of New Zealand between Stewart Island and Banks Peninsula, by Farran (1929) who noted the occurrence of several specimens in collections taken from south of New Zealand and by Vervoort (1957) who recorded the capture of this animal south of Tasmania. This species is most probably a normal inhabitant of the upper mesoplankton of the West Wind Drift (Vervoort, 1957).

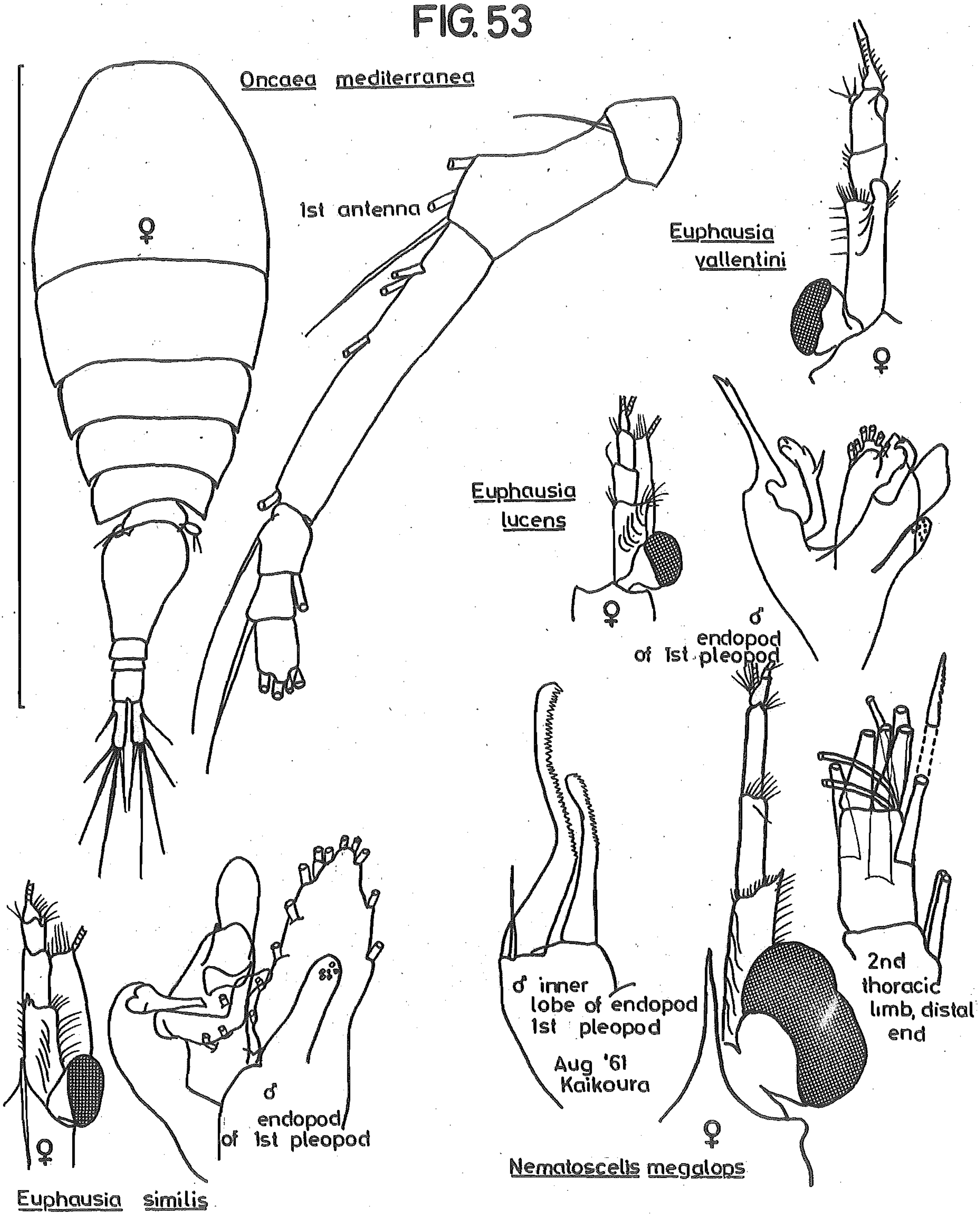
Labidocera cervi Kramer, 1895 Fig. 52

This species was captured at Kaikoura during June, July, August, September, October and December '64 and March and May '65. Labidocera cervi was captured previously in the New Zealand region by Bary (1951) in Cook and Foveaux Straits where it appeared to be subtropical in its main area of abundance, by Farran (1929) who recorded it from the north of the New Zealand region always close to the shore and from Melbourne Harbour, and by Dakin and Colefax (1940) who took it in N.S.W. coastal waters.

Oncaea mediterranea Claus, 1863 Fig. 53

This species was found in April, May, June, August, September, October and December '64, January, February, March, April and May '65 at Kaikoura. Oncaea mediterranea was recorded by Farran (1929) from the north and south of New Zealand and by Vervoort (1957) south of Tasmania. Oncaea conifera was recorded by both authors as accompanying this

FIG. 53


Oncaea mediterranea
♀
1st antenna
Euphausia vallentini
♀
Euphausia lucens
♀
♂ endopod of 1st pleopod
♀
♂ endopod of 1st pleopod
Euphausia similis
♂ inner lobe of endopod 1st pleopod
Aug '61 Kaikoura
2nd thoracic limb, distal end
♀
Nematoscelis megalops

species but was not identified in the Kaikoura zooplankton collections. *Oncaea mediterranea* is well distributed over tropical and temperate parts of the Atlantic, Pacific and Indian Oceans (Vervoort, 1957).

Euphausiacea

Nyctiphanes australis Sars, 1883 Fig. 52

This species was captured at Kaikoura in April, July, August, October, November and December '64, January and May '65. *Nyctiphanes australis* has been captured in the New Zealand region previously; it was recorded by Bary (1956) off the east coast of the South Island, by Tattersall (1924) from the north of New Zealand and by Sars (1885) and Sheard (1953) from the east coast of Australia. The distribution of *N. australis* covers southern subtropical neritic waters in the Australian region (Sheard, 1953).

Euphausia similis Sars, 1883 Fig. 53 also var. *armata* Hansen

This species and its variety was captured at Kaikoura during August, September and December '64 and January '65. *Euphausia similis* and *E. similis* var. *armata* were captured by Dr R. Pilgrim together off the Kaikoura wharf during August 1961 and identified by the late Mr K. Sheard. Previously Tattersall (1924) recorded the occurrence of *E. similis* var. *armata* from the north of New Zealand. *Euphausia similis* is found in all oceans; *E. similis* occurs in the north subtropical, tropical, south subtropical and subantarctic regions while *E. similis* var. *armata* is found only in the south subtropical and subantarctic regions (Sheard, 1953). In the Southern Hemisphere *E. similis* is confined to the region of the Subtropical Convergence (Sheard, 1953); that is, it occurs in the south of the subtropical zone and the north of the subantarctic zone.

Euphausia lucens Hansen, 1905 Fig. 53

This species was captured at Kaikoura during May, June, August, September, November and December '64, January, February, March, April and May '65. Previously E. lucens was captured by Tattersall (1924) to the south of New Zealand and by Bary (1956) off the whole of the east coast of the South Island. Sheard (1953) noted the restriction of E. lucens to the region of the Subtropical Convergence in all the Southern Hemisphere Oceans. It extends further into the subantarctic zone than the subtropical zone. The southern distribution of E. lucens was emphasised by the work of Bary (1959a) as he found that species characterised his northern subantarctic water.

Euphausia vallentini Stebbing, 1900 Fig. 53

This species was captured during June and August '64. Previously Bary (1956) recorded the occurrence of E. vallentini to the south-east of New Zealand and Tattersall (1924) noted the occurrence of this species in the subantarctic zone to the south of New Zealand. The distribution of this species is restricted to the southern subantarctic zone (Sheard, 1953).

Nematoscelis megalops? Sars, 1883 Fig. 53

This species was captured in May, June, August, November and December '64 and March '65 at Kaikoura. All specimens appeared to belong to the difficilis/megalops complex as there were long spines on both the ultimate and penultimate segments of the 2nd thoracic limb. No adult male specimens were caught at Kaikoura during the course of the study.

Male Euphausiacea specimens captured at Kaikoura during August 1961 and identified as N. difficilis by Sheard proved to have the inner lobe of the 1st pleopod endopodite identical with that described for N. megalops by Hansen (1911) (Fig. 53). This throws some doubt on Sheard's record of N. difficilis occurring in the Southern Hemisphere. Brinton (1962) supposed that the ranges of N. difficilis and N. megalops did not merge unless Sheard's records from Australia are substantiated. Thus it is very probable that N. megalops was captured off Kaikoura. Bary (1956) caught similar female specimens off the east coast of the South Island of New Zealand which he provisionally identified as N. megalops.

Nematoscelis megalops is subtropical in distribution in the southern Pacific Ocean (Sheard, 1953) although Brinton (1962) recorded that it was captured by the "Monsoon" expedition as far south as 54° 21'S south-east of New Zealand.

Thysanoessa gregaria Sars, 1883 Fig. 52

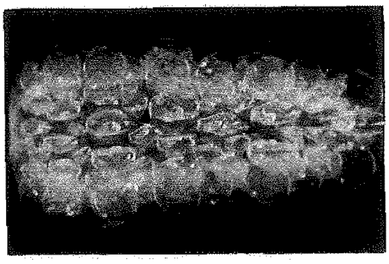
This species was captured during May, June, August, November and December '64, January, April and May '65 at Kaikoura. Thysanoessa gregaria was recorded previously in the New Zealand region by Bary (1956) who captured it off the whole of the east coast of the South Island in summer and by Tattersall (1924) who noted its occurrence north of New Zealand. Thysanoessa gregaria occurs in the subtropical regions of both hemispheres although it may extend a little into the southern subantarctic region (Sheard, 1953).

Tunicata

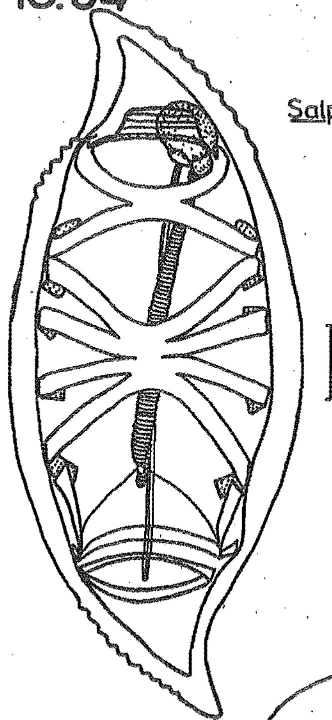
Ihlea magalhanica (Apstein, 1894) Fig. 54

This species was captured during April and May '64 and April '65. It was recorded by Bary (1959a) off the east coast of New Zealand from Dunedin to Kaikoura and by Thompson (1948) in the south-east Australian region. Thompson (1948), who found I. mahalhanica occurring in Australian regions where the temperature ranged from 11·6 to 22·25°C, considered it an indicator of the northern extension of colder water conditions although it is obviously indicative of warm water influence in the New Zealand region. The distribution of I. magalhanica may be summarised as southern subtropical.

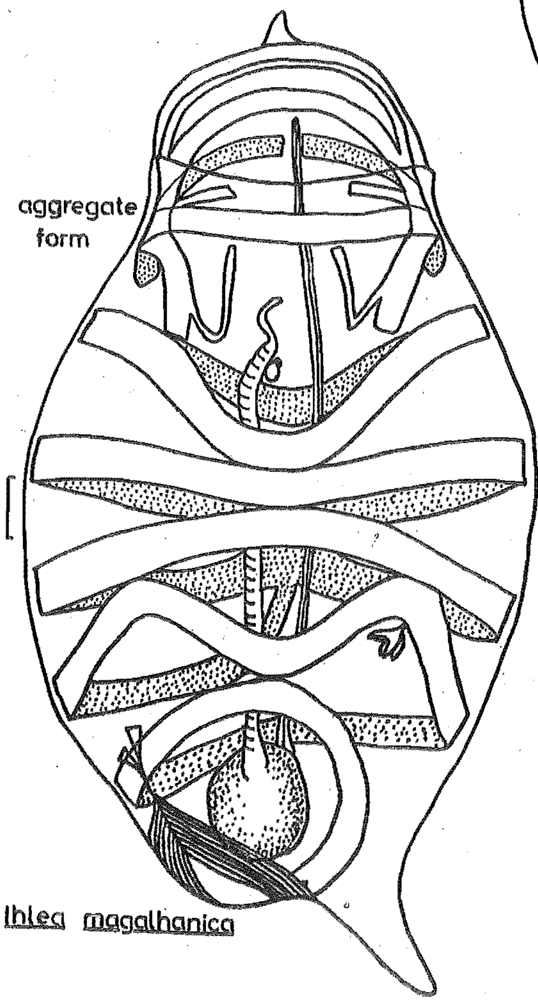
FIG.54



Pyrosoma atlanticum ?

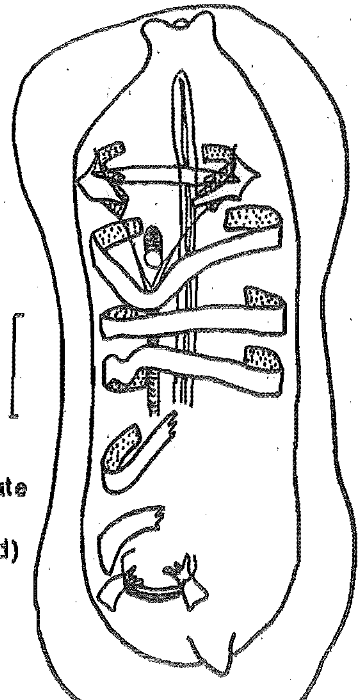


Salpa thompsoni
aggregate form



aggregate form

Ihlea magalhanica



aggregate form (damaged)

Thalia democratica

Thalia democratica (Forskal, 1775) Fig. 54

This species was captured on only one occasion (January, '65) at Kaikoura. Previous records of T. democratica are to be found in Bary (1959a) who caught it off the east coast of New Zealand from Dunedin to Cook Strait during summer, and in Thompson (1948) who noted it to be common off the south-east coast of Australia. Thompson considered T. democratica to be a subtropical species tolerant of colder conditions while Bary (1959a) used this species to indicate subtropical influence to the east of New Zealand. Thalia democratica is widely distributed in all tropical and temperate seas; all Australian specimens were found within the temperature range 11·5 to 25·6°C.

Salpa thompsoni Foxton, 1961 Fig. 54

This species was found at the "Permanent Station" during January '65. Salpa thompsoni was described by Foxton (1961) as being found only south of the Subtropical Convergence. Bary (1960) noted a species of Salpa which he called S. fusiformis f. aspersa. He plotted its occurrence on a salinity-temperature diagram and found that it had a subantarctic distribution with greatest concentrations occurring off the south-east of New Zealand, although specimens were also found as far north as Cook Strait. Undoubtedly Bary had captured S. thompsoni. This cannot be verified from his figure as the aggregate form was drawn with the IV and V muscles not in contact, a characteristic of Salpa aspersa.

Pyrosoma atlanticum? (Peron, 1804) Fig. 54

This species was captured at Kaikoura during April, May, June, August and September '64 and April '65. The identity of the Pyrosoma sp. was not verified, but it was most likely to be P. atlanticum as the only other species recorded off New Zealand by Bary (1960) was P. spinosum represented by a single specimen from the vicinity of Kaikoura. Bary (1960) recorded P. atlanticum to the east of Stewart Island in January and in large numbers off Dunedin during March 1951. Pyrosoma atlanticum was taken commonly off the east coast of Australia from Sydney to the south of the Tasmanian region, that is, from 35^{o}- 44^{o}S (Thompson, 1948).

b) The Zooplankton as Indicators of Water Movement

It has been shown in Section B that several types of water influenced the Kaikoura "Permanent Station" during the period of this study. These were coastal and oceanic water, subantarctic and subtropical water, and subsurface water.

The geographical and environmental limits of many zooplankton species have been wholely or partly described. Species, captured at the "Permanent Station", which had previously described distributions showing their possible usefulness as "indicators", were dealt with in section a).

In this section the intention is to show that the movement of the above water masses may have been indicated by their contained animals. This will be done under the following headings:

a) Indicators of Oceanic and Coastal Water
b) Indicators of Subtropical and Subantarctic Water
c) Indicators of Vertical Water Movements

a) Indicators of Oceanic and Coastal Water

The differences between the oceanic and coastal water zooplankton populations will be considered under four headings:

(i) Occurrence of Sagitta gazellae,
(ii) Number of Oceanic Species of Copepoda Present (on any sampling day),
(iii) Quantitative Occurrence of Calanus tonsus and
(iv) Occurrence of Subtropical Convergence Region Species.

Table 6: Occurrence of Sagitta gazellae and of Salinity $34 \cdot 65^{o}/oo$ at less than 150m Depth

	Salinity Greater than $34 \cdot 56^{o}/oo$ above 150m	<u>Sagitta gazellae</u>
1964 14 Apr.	x	
30 Apr.	x	
16 May	x	
1 June		
15 June	x	x
26 June	x	x
12 July		
2 Aug.	x	x
16 Aug.		
29 Aug.		
13 Sept.		
26 Sept.	x	x
11 Oct.		
29 Oct.	x	
17 Nov.	x	x
5 Dec.	x	x
21 Dec.	x	x
1965 7 Jan.	x	x
24 Jan.	x	x
24 Feb.	x	x
12 Mar.		
4 Apr.		
18 Apr.		x
5 May		

Table 7

OCCURRENCE OF OCEANIC AND COASTAL SPECIES OF COPEPODA

	'64 14 iv	30 iv	16 v	1 vi	15 vi	26 vi	12 vii	2 viii	16 viii	29 viii	13 ix	26 ix	11 x	29 x	17 xi	5 xii	21 xii	'65 7 i	24 i	24 ii	12 iii	4 iv	18 iv	5 v
OCEANIC SPECIES																								
Calanus tonsus								x			x		x	x	x	x	x	x	x					
Calanoides carinatus											x	x	x	x	x				x					
Neocalanus gracilis		x	x		x																	x		
Eucalanus elongatus	x											x		x	x			x			x		x	
Eucalanus longiceps	x				x		x				x	x	x	x	x		x	x	x	x	x	x		
Rhincalanus nasutus				x																				
Mecynocera clausi			x		x												x							
Aetideus armatus	x											x							x	x		x	x	
Euaetideus giesbrechti	x																							
Aetideopsis multiserrata													x									x		
Chiridius gracilis				x																				
Euchirella rostrata																x	x							
Euchirella sp.											x	x												
Euchirella venusta																			x					
Undeuchaeta plumosa																			x					
Euchaeta sp.				x									x	x										
Phaenna spinifera																							x	
Metridia lucens	x		x	x	x	x	x	x		x	x	x	x	x	x	x		x	x			x	x	x
Pleuromamma abdominalis	x		x	x				x											x					
P. xiphias																			x					
P. gracilis	x	x	x	x	x	x		x	x		x	x	x		x	x		x	x		x	x		x
P. robusta				x	x	x		x											x					
Centropages bradyi	x		x														x							
Lucicutia flavicornis					x			x											x					
Haloptilus oxycephalus																			x					
Candacia cheirura		x	x			x		x			x	x			x		x	x	x					
Oncaea mediterranea	x	x	x			x		x			x	x	x			x	x	x	x	x	x		x	x
COASTAL SPECIES																								
Labidocera cervi						x	x			x	x		x	x		x					x			x
Oceanic - Coastal spp.	9	4	8	7	7	4	1	8	1	0	7	9	7	5	7	4	7	7	15	3	3	6	5	2

(i) Occurrence of *S. gazellae*

Sagitta gazellae was identified and found to occur in certain horizontal and N70 vertical hauls. Amongst the horizontal hauls this animal was found on 26 September at 85m; 17 November at 91 and 150m; 5 December at 79m; 21 December at 90 and 137m; and 24 February at 91m. In addition *S. gazellae* was found to be present in N70 samples taken on other dates at the "Permanent Station". These dates were 15 and 26 June and 2 August'64; also 7 January and 18 April '65.

When all these occasions are considered together it may be seen with reference to Fig. 58 that when *S. gazellae* was captured a salinity greater than 34·65°/oo was found above 150m. Conversely, not all occasions when a salinity greater than 34·65°/oo was found above 150m were days on which *S. gazellae* were captured. These events are recorded in Table 6.

Thus *S. gazellae* appeared ten times out of fifteen in conjunction with the arbitrary salinity limit of 34·65°/oo at 150m. Other factors which appear to be limiting this animal will be considered later.

(ii) Number of Oceanic Species of Copepoda Present

Table 7 lists most of the oceanic species of Copepoda found at the "Permanent Station", excluding those that were present all the year round and those whose identities are not certain. One coastal species *Labidocera cervi* is included. The sum of all instances when oceanic species occurred was calculated and any occasion when *L. cervi* was present, subtracted. These figures are graphed in Fig. 55.

In Fig. 55 the fluctuations in the winter number of oceanic Copepoda species were to be expected although a direct connection with the hydrology was not evident except on 29 August '64 when a predictable minimum occurred. Figs

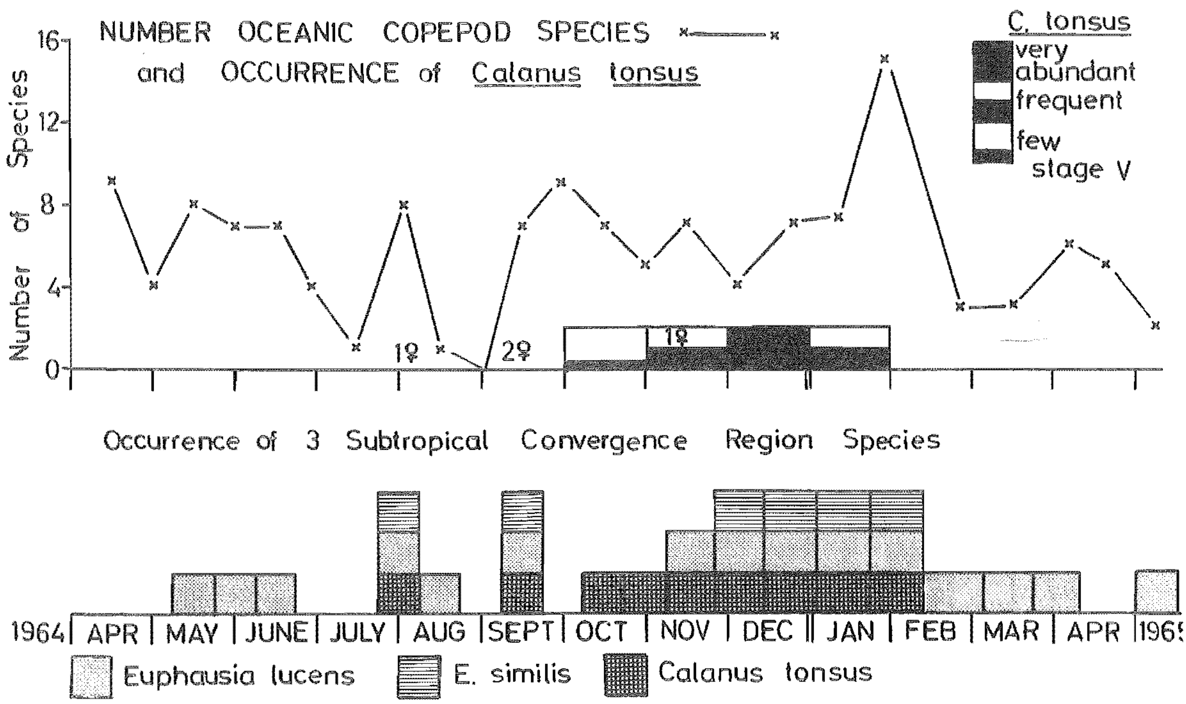


Fig. 55: The Seasonal occurrence of the number of oceanic Copepod species, Calanus tonsus, and three "Convergence Region" species at the Kaikoura "Permanent Station"

57 and 58 show the complete coastal nature of the water column on that date. The period from September '64 to the end of January '65 showed smaller fluctuations in the number of oceanic Copepod species but it was expected that the December values would have been greater. (See following section, (iii)) The decrease in oceanic species present at the end of February and March '65, the increase on 4 April and the second decrease on 18 April and 5 May '65 was in agreement with the hydrological data (Figs 57 and 58).

(iii) Quantitative Occurrence of *Calanus tonsus*

This species was described by Vervoort (1957) as occurring over the whole of the Pacific Ocean and as being particularly characteristic of the subantarctic epiplankton. He found *C. tonsus* very abundant in the New Zealand region and south of Australia indicating that this Copepod reaches maximum numbers in the region of the Subtropical Convergence. Bary (1951) used this species as an indicator of coastal water as the prolific hauls were made in coastal waters, although he noted its disappearance when subantarctic influence was strong. Nevertheless, this Copepod is not restricted to any one environment, and it occurred at the "Permanent Station" when oceanic influence was particularly strong. Thus *C. tonsus* will be considered as an indicator of oceanic water influence. The approximate abundance of this Copepod is indicated on Fig. 55. The numbers of the stage V copepodites waxed and waned with the summer oceanic water influence (shown in Fig. 58), while an occasional adult female occurred during the preceding months, August and September. On the 5 and 21 December '64 *C. tonsus* was found in concentrations of $3140/m^3$ at 5m and $4425/m^3$ at 20m respectively. The relatively low numbers of oceanic Copepod species occurring in December coincided with the tremendous concentrations of *C. tonsus*. It is possible that rarer species of Copepoda were excluded by the swarming *C. tonsus* from the position sampled.

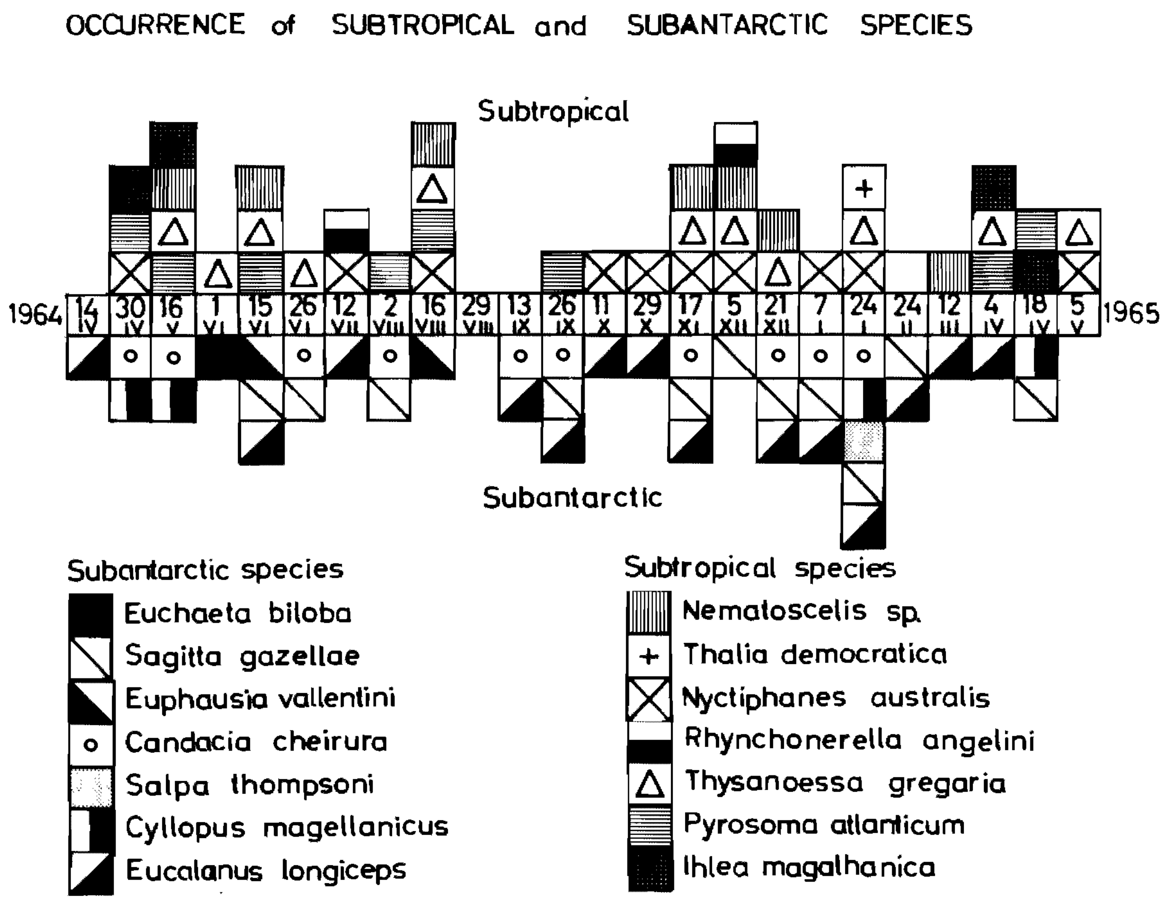


Fig. 56: The occurrence of selected Subantarctic and Subtropical animals at the Kaikoura "Permanent Station"

(iv) Occurrence of Subtropical Convergence Region Species

Three species were found at the "Permanent Station" which are apparently limited or have their main concentrations in the region of the Subtropical Convergence. These species are C. tonsus and two of the Euphausiacea, Euphausia lucens and E. similis (Vervoort, 1957 and Sheard, 1953). The occurrences of these species are noted in Fig. 55 where they may be compared with the numbers of oceanic Copepoda and the quantitative appearance of C. tonsus. Supposedly these animals should give the best indication of oceanic water conditions. The sum of occurrences of these three species, nevertheless, follows a pattern similar to that indicated by the Copepod species numbers.

Discussion

These four methods of indicating the appearance of oceanic waters complement one another, especially during the period from November '64 to January '65 which was almost free from coastal influence. Winter oceanic water invasions were the hardest to detect in terms of the zooplankton as no criterion of temperature or salinity seems to have been consistently connected with animals considered to be of oceanic origin. One of the strongest winter invasions of warm oceanic water occurred on 26 June '64, yet none of the four methods record this except that S. gazellae was present.

(b) Indicators of Subtropical and Subantarctic Water

Amongst the zooplankton certain species were found at the "Permanent Station" which are known to have a distribution limited to either the subantarctic or the subtropical zone.

Those species (section E(a)) which have a subtropical distribution are: Thysnaoessa gregaria, Nematoscelis sp. and Nyctiphanes australis (Sheard, 1953); Rhynchonerella angelini (Tebble, 1960); Pyrosoma sp., Ihlea magalhanica and Thalia

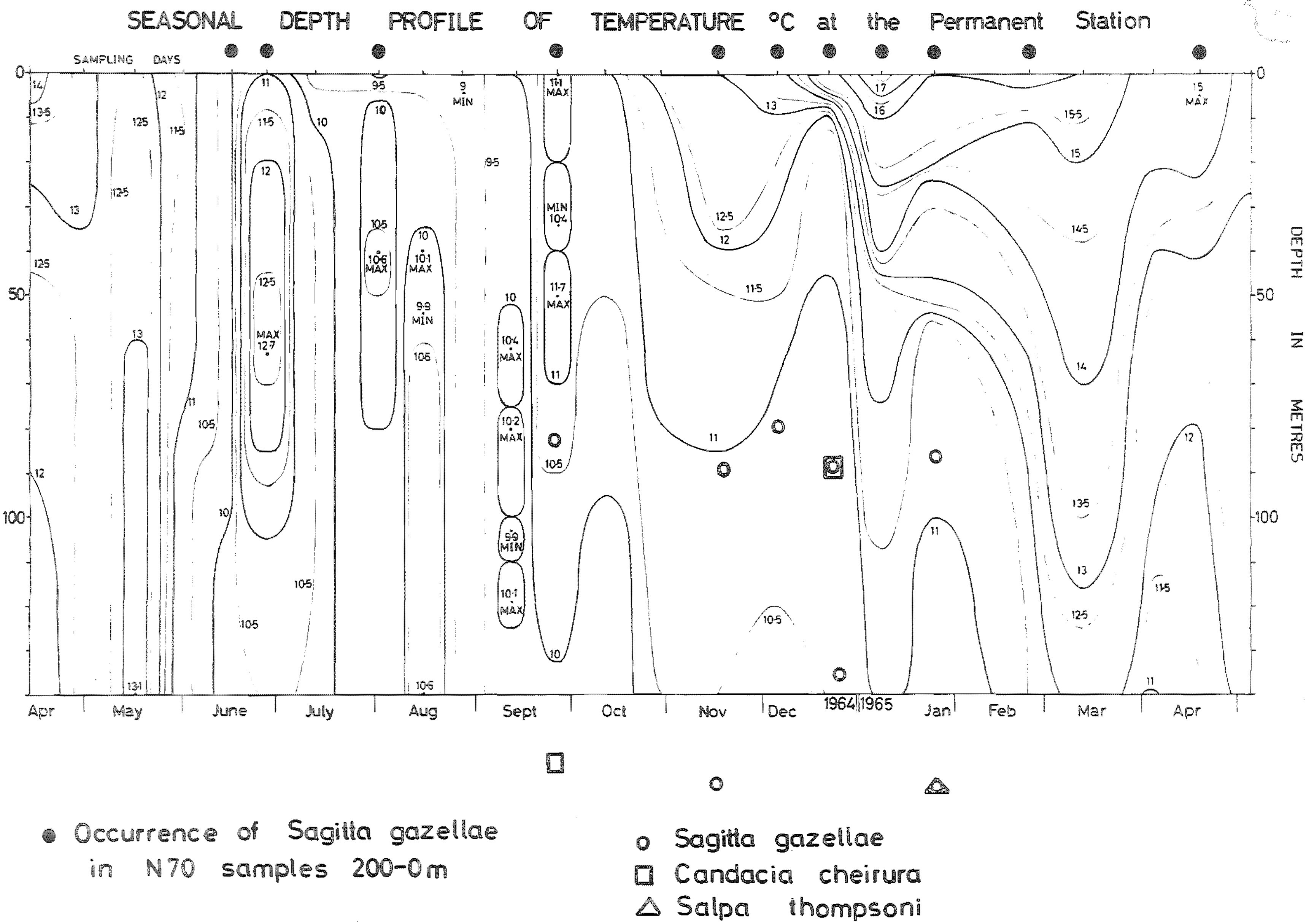


Fig. 57: Occurrence of Subantarctic species, <u>Sagitta gazellae</u>, <u>Candacia cheirura</u> and <u>Salpa thompsoni</u> with respect to temperature

democratica (Thompson, 1948).

Species having a subantarctic distribution were Euphausia vallentini (Sheard, 1953); Candacia cheirura and and Euchaeta biloba (Vervoort, 1957); Sagitta gazellae (David, 1955); Cyllopus magellanicus and Eucalanus longiceps =E. acus (Bary, 1959a); and Salpa thompsoni (Foxton, 1961).

The occurrence of each of these species is plotted in Fig. 56. It may be seen that both subtropical and subantarctic animals occurred together, and observation not inconsistent with the fact that the "Permanent Station" was situated in the region of the Subtropical Convergence. The appearance of all the above species except N. australis depended on the degree of oceanic water influence. It is particularly evident that occasions when no subtropical and/or subantarctic animals were recorded in Fig. 56 were days when some degree of coastal water influence was being exerted. (See Figs 57 and 58)

The appearance of a peak number of subantarctic species on 24 January '65 prompted the investigation of the vertical distribution of these species from records of their occurrence in horizontal haul samples. When the distribution of three subantarctic species (S. gazellae, S. thompsoni and C. cheirura) with depth is considered on the Seasonal Depth Profile of Temperature (Fig. 57) it is seen that none of the species were recorded at a temperature greater than 11°C. No horizontal hauls were taken between the depths of 22m and 80m, but it is noteworthy that none of the above species were captured during the horizontal hauls on 7 January '65 when no samples were taken in water colder than 11°C. Those species considered in Fig. 56 as subtropical were discovered at the surface during the period November to January but were also recorded from the deepest depths sampled.

SEASONAL DEPTH PROFILE OF SALINITY ‰ at the Permanent Station

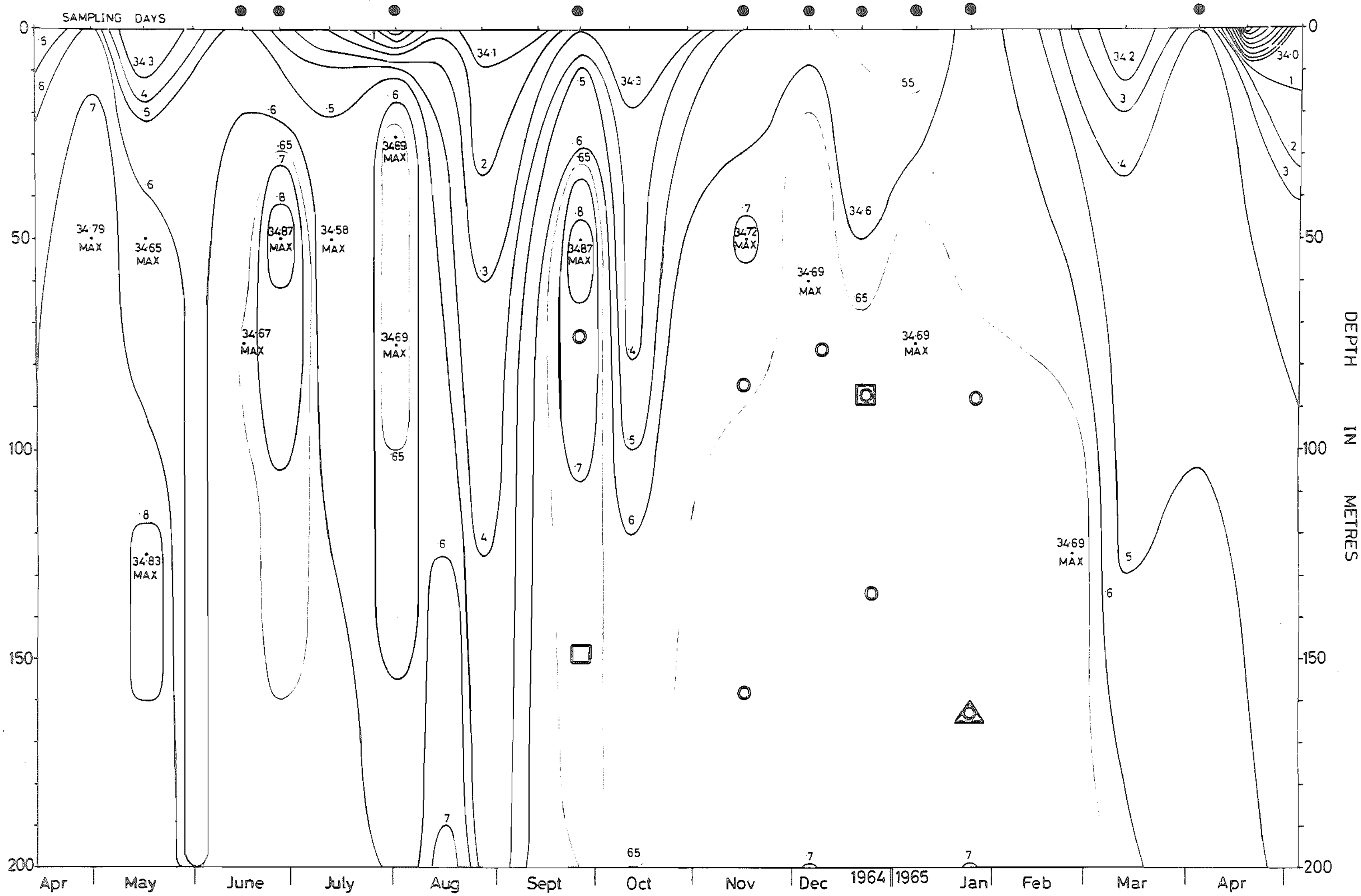


Fig. 58: Occurrence of Subantarctic species Sagitta gazellae, Candacia cheirura and Salpa thompsoni with respect to salinity

Discussion

Although subtropical and subantarctic species nearly always occurred together, the evidence collected during the summer indicated that at least one species (S. gazellae) was limited vertically to water cooler than 11°C. This information, considered with the salinity criterion of 34·65°/oo above 150m (previously introduced), indicates the conditions which limited the distribution of S. gazellae at the "Permanent Station" except on 18 April '65.

(c) Indicators of Vertical Water Movements

Several species of Copepoda were captured during the course of this study which have been shown in the past to have a distribution restricted to the depths. These species are: Euchaeta biloba, Pleuromamma robusta and Euaetideus giesbrechti, all of which Vervoort (1957) restricts to depths greater than 200m; Haloptilus oxycephalus, Aetideus armatus and Candacia chairura (Vervoort, 1957) and Euchirella rostrata (Rose, 1933) which are confined to depths greater than 100m; and Eucalanus elongatus (Vervoort, 1957) which is usually found below 100m but may be caught in considerable numbers at the surface.

Of these species only two occurred at positions which were significantly outside their ranges. P. robusta was found at 22m on 26 June '64 and H. oxycephalus at 5m on 24 January '65. E. elongatus occurred on 1 June '64 and 24 January '65 at 5m.

Discussion

The appearance of P. robusta near the surface on 26 June '64 indicates that the strong invasion of high temperature and high salinity water on the same date must have produced or have been produced by a movement of water from at least 200m depth. The high winter nitrate values support this hypothesis. The appearance of H. oxycephalus at the surface on 24 January '65 indicated that the rise of isotherms on that date must have been brought about by a vertical movement of water. There is no evidence from the zooplankton that similar water movements took place on 21 December and April '65. The evidence from the occurrence of E. elongatus is rejected as this species is not rigidly confined to depths greater than 100m.

CONCLUSIONS

An approximate indication of oceanic water influence was shown in the number of oceanic Copepod species and the occurrence of the three convergence region species. Uninterrupted oceanic influence was recorded in the appearance of C. tonsus while oceanic water of subantarctic origin (that is, below 11°C) was accompanied by S. gazellae.

The "convergence" nature of the "Permanent Station" was shown as both subtropical and subantarctic species usually appeared together, depending on coastal water influence. Not all species captured were tolerant of the whole temperature range found. S. gazellae was one such intolerant species which confirmed the fact that subtropical water overlaid subantarctic water during summer.

The occurrence of P. robusta and H. oxycephalus near the surface on two days indicated the possibilities of vertical water movements having taken place.

F. FINAL DISCUSSION

The hydrological situation in the Kaikoura region was known from the work of Garner (1961) and Houtman (1965) to be complex. During the course of this study it was discovered that the characteristics of the "Permanent Station" were primarily coastal, although fluctuating subtropical (oceanic) influence and varying discharge from the rivers in the region caused the coastal characteristics to fluctuate also; oceanic influence was more constant during summer. Subtropical water, indicated by high temperatures and salinities, was introduced into the region below the surface in winter and at the surface in summer. Upwelling of cold water occurred on at least 21 December, while surface water replaced deeper water layers on 12 March. The movements of water described here produced a high winter level of nitrate and enriched the surface layers on at least two occasions: the end of September and 21 December '64.

As one of the aims of this study was to determine if the above complex hydrological situation did exert an appreciable effect on the plankton, the definitions of the seasonal cycle were compared with cycles from regions similar in most respects. From these comparisons it was seen that some characteristics of the plankton were similar to those with which they were being compared while other aspects exhibited obvious differences. All these findings will now be considered under the following headings:

Quantitative Distribution of Phytoplankton

The Kaikoura phytoplankton showed certain similarities to the phytoplankton in other regions. The most obvious similarity was the conspicuous spring bloom, while the general levels of chlorophyll a detected and the "gross" primary production calculated were in accord with figures given by other workers (Humphrey, 1960; Ryther and Yentsch, 1958).

Certain factors were deduced, with some certainty, as having exerted a controlling influence on the phytoplankton population. Evidence that the critical low level of mean surface radiation, 0·03 g cal/cm^2/min. (Ryther, 1963), was not reached at Kaikoura and that the phytoplankton was mixed throughout the water column to 200m during July (Fig. 17) led to the conclusion that the stability of the water column was the main controlling factor in the commencement of the spring phytoplankton bloom. Similarly, the stability factor contributed, through the shallower depth and the lower latitude of Humphrey's (1960) Sydney station, to the earlier manifestation and greater magnitude of the Sydney spring phytoplankton bloom.

The only occasion when the grazing of the zooplankton was definitely responsible for a reduction in the phytoplankton biomass was during the period from the beginning of December to the beginning of February, when the Copepod Calanus tonsus was present in large numbers. On 21 December this species was found at 22m as a biomass of 6200 mg/m^3 which is three times greater than the concentration of 1999 mg/m^3 recorded by Sheard (1947) off MacRobertson Land (Antarctica) during February 1931. Even though the numbers of C. tonsus had become reduced by 7 January, some lag was recorded in the recovery of the phytoplankton population to the level that was retained approximately until the stratification of the water column began to break down in May '65.

The complex hydrological situation, as it effected increases in the level of nitrate in the upper water layers, could have been the factor sustaining the spring phytoplankton growth over a period greater than the spring bloom at Humphrey's (1960) Sydney station. Also, the increased concentrations of phytoplankton, compared with Sydney figures from January onwards, may be attributed to the same cause although it is possible that the low level of zooplankton grazing (Fig. 21) also contributed. It was noteworthy that although this higher level of phytoplankton was retained after January, at no stage was the surface nitrate reduced to the levels found from the end of September to the beginning of December. From this it may be deduced that the phytoplankton population could have grown to greater concentrations; but something was preventing extra growth from occurring. A comparable situation was found in an area off the south-west coast of Africa, with supposedly recently upwelled water which contained little phytoplankton (Steeman Nielsen and Aabye Jensen, 1957). Andersen and Banse (1961) considered the problem and concluded that the "difficulty of seeding cool water, and the physical effects of dilution of the initial population by newly upwelled water, along with vertical instability are significant components."

The invasions of oceanic water produced chlorophyll a maxima, more often than not, at depths greater than those that would have resulted had there been no such invasions, as the transparency of the water at the "Permanent Station" was very low.

Quantitative Distribution of Zooplankton

The zooplankton at Kaikoura exhibited characteristics in common with populations from other regions. Amongst those animals adequately sampled, all showed that the main period of increase during one year was linked with the food supply of those animals. Thus all planktonic groups of animals, except the predators (Ctenophora and Chaetognatha), had their main or initial increase during August and September, the period of the spring phytoplankton bloom. The manner in which all animal groups were most frequently distributed with depth was in agreement with their feeding habits.

Some zooplankton groups were inadequately sampled as their size and swimming ability made it easy for them to avoid capture. These groups were the adult Euphausiacea and Amphipoda, and some of the larger Decapod larvae. Other groups had representatives which appeared in substantial numbers for only part of the year, thus distorting the overall picture; several species of Salp appeared only in summer with the highest temperatures while the Chaetognatha *Sagitta gazellae* and the Copepod *Calanus tonsus* were both recorded in large numbers in the more constantly oceanic water during summer.

The average biomass of 68mg/m^3 recorded during the course of this study at Kaikoura was approximately similar to the values 0-50mg/m^3 (Tranter, 1962) for subtropical oceanic regions. But the "Permanent Station" did not follow a pattern of continuous depletion of nutrients to be expected from oceanic surface waters. The chlorophyll *a* data also suggest that the phytoplankton population could have supported a greater concentration of zooplankton than was present during most of the period studied. Having eliminated the effect of two important controlling factors (depth and food) the only remaining obvious explanation for the sparse zooplankton population lies in the disturbed hydrological situation. Another aspect of the annual cycle of zooplankton at Kaikoura was the rapid fluctuation in both biomass, and numbers of predominant groups (Copepoda and Euphausiacea). A similar situation was recorded by Tranter (1962) and he suggested that the rapid fluctuations indicated a lack of stability in the environment.

As already shown, the region of the "Permanent Station" was invaded by bodies of water foreign to that region: invasions of subtropical (oceanic) water and vertical water movements occurred. There were two ways in which the zooplankton population may have been reduced: by the introduction of animals into unfavourable environments so that they are not able to reproduce at optimal rates, if at all, and by the physical effect of dilution of the initial population. The Copepod species *Calanus tonsus* appears to be the one animal that was not affected by the disturbed situation. It is assumed that C. tonsus is parthenogenteic, since no males have ever been found. This species apparently finds the characteristics of the near-shore environment favourable for breeding to swarm proportions.

Chemical Composition of the Zooplankton

The Kaikoura plankton as defined by % $\frac{\text{Organic Matter}}{\text{Dry Weight}}$ was found to be typical of slope water and distinct from well-fed coastal plankton and Sargasso Sea plankton as characterised by Riley et al (1949). It was shown that the presence of Salps in the water did not indicate a great increase in organic matter content of the plankton as might be suggested by the wet weight alone.

Expected seasonal differences in the organic matter composition of the plankton in general were detected in the % $\frac{\text{Organic Matter}}{\text{Dry Weight}}$ content of the total plankton catch minus Salps and Euphausiacea. The greatest values were obtained during spring and summer indicating the condition put on by most animals when the food supply was good.

The % $\frac{\text{Organic Matter}}{\text{Wet Weight}}$ of the Euphausiacea was interpreted as showing a latitudinal effect on the storage of fat, thus indicating that Euphausids had been introduced to the Kaikoura region from further north. This conclusion was reached from evidence in Riley and Gorgy (1948) and Sheard's observations in Thompson (1942) that in the south-east Australian region there appeared to be an increase southwards in the oil content of certain Copepoda and Euphausiacea species. Also, the three occasions (April to May, and June '64, and January to April '65) when the % $\frac{\text{Organic Matter}}{\text{Wet Weight}}$ was below 10% were nearly all instances when subtropical water was influencing the "Permanent Station".

Species Composition of the Zooplankton

The general structure of the Zooplankton population itself was very similar to a "Calanus" community in the North Atlantic recorded by Raymont (1963) with one or two minor differences: amongst the Copepoda the genus Pseudocalanus was replaced at Kaikoura by Clausocalanus; Pleuromamma gracilis played an important part in the Kaikoura population; and the genus Euchaeta was relatively unimportant although present in greater numbers below 200m at Kaikoura. Into this community comprising nine common species of Copepoda, one common species of Chaetognath, one common Amphipod species, two common species of Euphausiacea, and Pleurobrachia pileus, the Ctenophore, were introduced various other species of a more sparse occurrence but with previously recorded affinities for distinct bodies of water.

The numbers of oceanic species of Copepoda recorded at the "Permanent Station" on each sampling day were found to correspond approximately to the existing hydrological situation: during summer there was a consistently greater number of oceanic species present than in winter with the maximum number recorded being fifteen on 24 January. The Copepod Calanus tonsus was used as an indicator of oceanic water to complement the numbers of oceanic Copepod species, and a similar indication of oceanic influence was gained from the addition of the number of convergence region species captured on each sampling day. It is possible that by the same oceanic water movement after December Nytiphanes australis, a neritic Euphausiacean, was excluded from the region of the "Permanent Station".

The "Convergence" nature of the "Permanent Station" was confirmed by the presence of both subtropical and subantarctic species. The most spectacular occurrence in June and August was that of Euphausia vallentini, a species usually restricted to the southern subantarctic region. Another subantarctic species, Sagitta gazellae, was captured only on those occasions when a salinity of 34·65°/oo was found above 150m and in water cooler than 11°C. It was not possible to define the limits of other species for as far as could be ascertained all had a fairly wide tolerance of conditions recorded at the "Permanent Station".

It is fairly certain that vertical water movements took place in summer as well as winter. The appearance of Pleuromamma robusta (usually found below 200m) at 22m and Haloptilus oxycephalus (usually found below 100m) at 5m on 26 June '64 and 24 January '65 respectively and the surface characteristics of the subsurface plankton on 12 March '65 complement the hydrological data.

During the year of this study, shoals of Kahawai (Arripis trutta) disappeared almost completely from the Kaikoura region from the beginning of January to the end of March 1965. This situation appears to have been unusual on the evidence of local fishermen, and was certainly different from the year before when Stonehouse (1965) recorded shoals of fish off Kaikoura all through summer. The disappearance and reappearance of adult Euphausiacea from the plankton collections tied in with movements of the Kahawai in the 1965 summer. Thus the dependence of the Kahawai on the Euphausiacea for food is demonstrated. The Euphausiacea, although strong swimmers, are influenced by the same hydrological disturbances that affected the Copepoda since the Euphausiacea depend for a greater part of their food on the faecal pellets of the Copepoda.

On the preceding evidence it is obvious that the fluctuating environmental disturbances affected, to varying degrees, the appearance of Kahawai shoals through their ultimate reliance on the plankton, as food. This conclusion would be very important to any pelagic fishery planned for the Kaikoura region.

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APPENDIX I

Phytoplankton Diversity and Succession

Methods

When the extinction of Phytoplankton pigments in acetone was measured (page 18) a measurement at 4300 Å was added to enable the quotient D430/D665 to be calculated as used by Margalef (1962).

Introduction

When a small sample is taken from an animal population there are two extreme situations which may be observed:

1) all the individuals are of the same species, or
2) every individual belongs to a different species.

The wide range of diversity possibilities that lie between these two limits is best expressed as a "diversity index". For example:

$$d = \frac{S - 1}{\log_e N}$$

where S = number of species and N = number of individuals.

$$E_n = \frac{1}{N} \log \frac{N!}{N_a! N_b! N_c! N_d! ---}$$

where N_a, N_b, N_c, --; N are the numbers of species a,b,c,--; and N is the total number of individuals.

d and E_n are the diversity indices (Margalef, 1960).

Margalef (1958) has shown that the diversity index increases with the state of succession. He summarised the general pattern of phytoplankton succession into three stages. The first stage has small-celled diatoms with a high rate of potential increase. This stage has a high production:total biomass ratio and low diversity. The second stage has a mixed community with bigger cells, a lower rate of increase, and higher diversity. Stage three has a dominance of free-swimming species, mainly dinoflagellates, with a low potential rate of increase, a low production:total biomass ratio, and the greatest diversity.

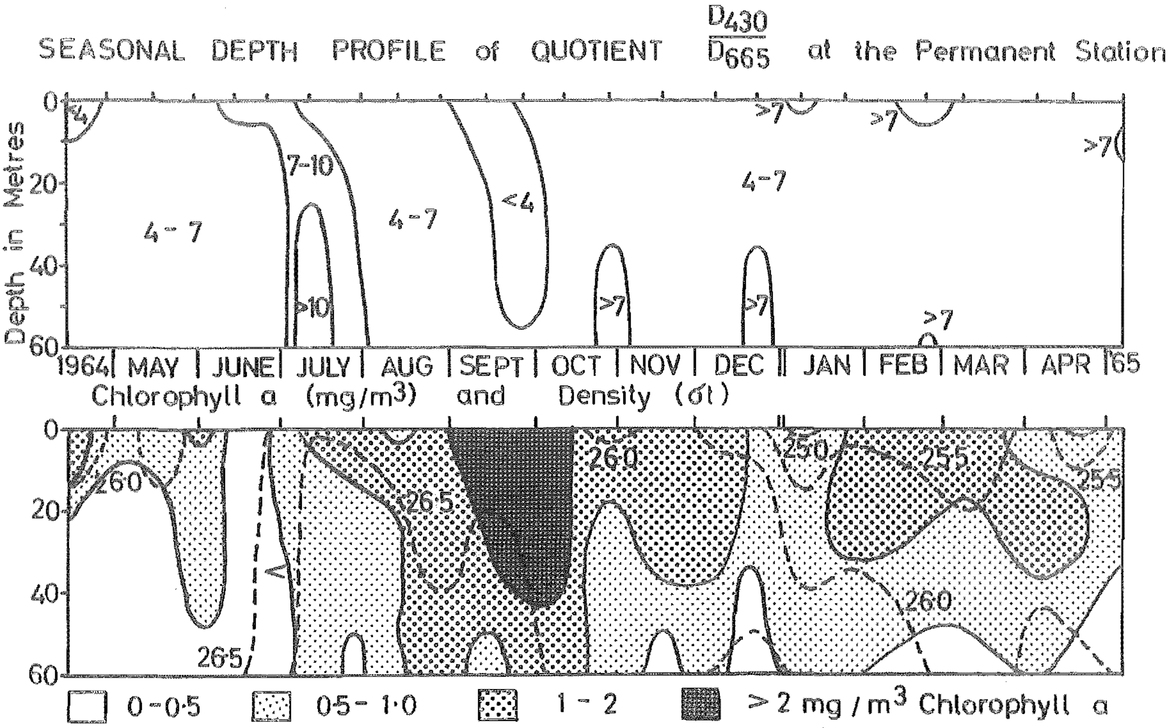

Fig. 59: Seasonal Depth Profiles of Quotient $\frac{D430}{D665}$, chlorophyll a and Density σt at the Kaikoura "Permanent Station", 1964-65

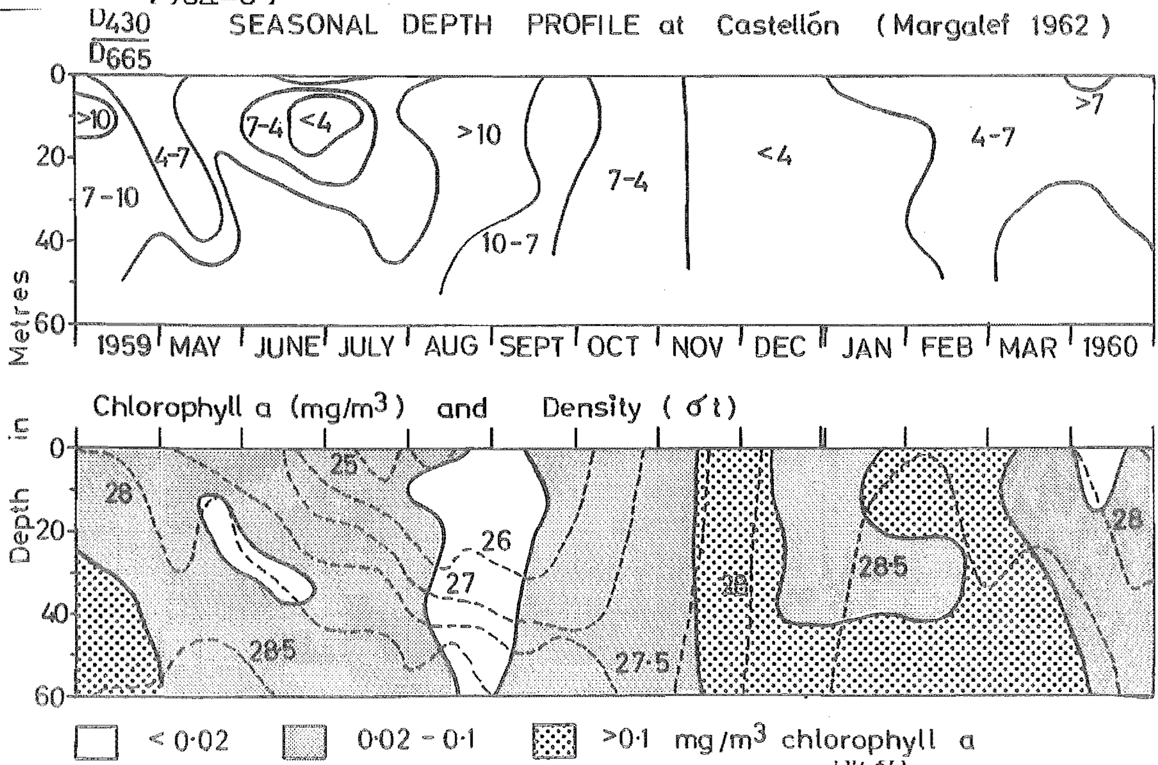

Fig. 60: Seasonal Depth Profiles of Quotient $\frac{D430}{D665}$, chlorophyll a and Density σt at Castellón (Mediterranean) 1962

Subsequently Margalef (1961) showed a correlation between the diversity index and $\frac{D430}{D665}$ which he interpreted as the "pigment diversity quotient". This quotient increased when the phytoplankton community diversity increased, accompanied by a decrease in production:total biomass, and with depletion of nutrients.

Results and Discussion

The "pigment diversity quotient" was calculated as a seasonal depth profile for Kaikoura (Fig. 59) and may be compared with similar figures from Margalef (1961)(Fig. 60). The seasonal profiles are remarkably similar in pattern, differing only in the duration of certain pigment diversity values. But when this pattern is considered in relation to the density (σt) profile (Figs 59 and 60) it may be seen that similar diversity ratios were obtained at different stages of the σt cycle. For example, the highest values of the quotient $\frac{D430}{D665}$ in the Mediterranean occurred when the thermocline was well developed and the concentration of nutrients was low. Whereas at Kaikoura the high values of $\frac{D430}{D665}$ occurred at the end of the winter when there was a high concentration of nutrients and the water column hardly stratified.

It is worth noting that at both these instances dinoflagellates were present; *Peridinium* sp., *Dinophysis* sp., and *Ceratium* sp. were present in the Mediterranean and *Ceratium* sp., and *Peridinium* sp. were present at Kaikoura. *Ceratium tripos* was particularly abundant at Kaikoura on 12 July '64. Its presence caused the net phytoplankton to be coloured red-brown.

Peridinians in general are able to exist at lower nutrient levels than diatoms (Raymont 1963), hence their occurrence in the Mediterranean, but there is evidence (Braarud in Raymont 1963) that *Ceratium* sp. and *Peridinium* sp.

reproduce more quickly at lowered salinities which would explain the Kaikoura situation.

The period of increase in dinoflagellates at Kaikoura must have had a higher rate of production (i.e. a greater production:total biomass ratio) than the period of winter that preceded it. Therefore, from Margalef's work, it would be expected that the diversity index was lowered. But the highest values of $\frac{D430}{D665}$ were found at this time. So it seems that a correlation between $\frac{D430}{D665}$ and the diversity index would not be found at Kaikoura. If the above supposition is correct then the pigment diversity quotient seems to be related to the increase and decrease in dinoflagellates rather than phytoplankton diversity in the Kaikoura region.

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APPENDIX II

Salinity, Temperature, Density, Chlorophyll a, Pigment Diversity Quotient and Nitrate found at the "Permanent Station" 1964-65

DATE	Sal. °/oo	Temp. °C	σt g/L	Ca mg/m^3	D430/D665	NO_2-NO_3 µg at/L	Depth m
1964							
14·iv	34·43	14·3	25·70	1·21	3·6	6·4*	0
	34·49	13·6	25·89	1·50	3·8	5·8*	10
	34·63	13·0	26·13	0·57	5·0	13·8*	25
	34·63	12·3	26·27	0·28	6·5	15·9*	50
	34·67	12·0	26·33	0·47	5·3	19·1*	75
	34·76	11·8	26·46	0·20	9·0	14·8*	100
30·iv	34·63	13·3	27·07	0·61	4·3	14·8*	0
	34·74	13·3	26·15	0·46	5·5	17·5*	25
	34·79	12·9	26·27	0·42	4·4	17·5*	50
	34·76	12·8	26·26	0·39	3·3	19·0*	100
	34·78				5·1	22·3*	200
16·v	34·29	12·6	25·94	0·87	4·2	12·7*	0
	34·29	12·6	25·94	0·49	4·3	12·2*	10
	34·54	12·9	26·08	0·38	5·0	12·7*	25
	34·65	12·9	26·16	0·38	5·0	13·2*	50
	34·63	13·1	26·11	0·39	6·5	12·2*	75
	34·83	13·1	26·26	0·42	4·4	13·2*	125
	34·76			0·19	6·8	14·8*	200
1·vi	34·33	11·2	26·23	1·05	5·5	13·0*	0
	34·51	11·5	26·32	0·83	4·0	10·6*	10
	34·52	11·3	26·37	0·77	6·1	11·6*	25
	34·56	11·1	26·43	0·51	4·5	19·3*	50
	34·56	11·0	26·45	0·45	5·1	22·8*	75
	34·56	10·8	26·49	0·51	5·6	19·3*	125
	34·60			0·26	8·2	20·7*	200
15·vi	34·56	10·5	26·54	0·42	8·5	17·9*	0

* Unreliable results

1964	°/oo	°C	g/L	mg/m³	D430/D665	µg at/L	m
15·vi	34·58	10·5	26·56	0·44	4·5	16·5*	10
	34·61	10·5	26·59	0·35	6·5	17·9*	25
	34·61	10·5	26·59	0·42	5·2	17·9*	50
	34·67	10·5	26·63	0·36	6·1	15·2*	75
	34·63	10·3	26·63	0·19	6·7	29·0*	125
	34·61			0·26	7·0	34·5*	200
26·vi	34·38	11·0	26·32	0·47	9·2	13·3	0
	34·52	11·6	26·31	0·50	5·6	12·0	10
	34·61	12·2	26·27	0·44	6·9	13·3	25
	34·87	12·6	26·39	0·37	5·2	15·5	50
	34·72	12·5	26·29	0·26	5·1	18·3	75
	34·69	10·7	26·42	0·13	7·5	19·7	125
	34·61			0·17	6·0	26·8	200
12·vii	34·20	9·2	26·48	1·28	6·1	13·2	0
	34·43	9·9	26·55	0·53	9·3	11·7	10
	34·52	10·2	26·56	0·61	10·1	13·0	25
	34·58	10·2	26·61	0·68	11·8	11·7	50
	34·56	10·2	26·59	0·65	16·1	11·7	75
	34·61	10·2	26·62	0·75	15·1	13·0	125
	34·63			0·80	20·3	15·6	200
2·viii	33·84	9·0	26·23	0·95	4·8	6·0	0
	34·49	10·2	26·53	1·15	4·7	9·1	10
	34·69	10·4	26·65	0·61	6·2	12·2	25
	34·67	10·5	26·63	0·47	7·1	11·0	50
	34·69	10·1	26·71	0·44	7·7	12·9	75
	34·61	9·7	26·73	0·27	8·2	12·9	125
	34·58			0·62	7·9	14·1	200
16·viii	34·18	9·4	26·44	0·82	4·7	4·8	0
	34·33	9·8	26·48	1·11	4·6	2·7	10
	34·40	9·8	26·54	0·94	4·6	2·7	25
	34·45	9·9	26·56	0·98	5·0	2·5	50
	34·54	10·6	26·51	0·87	4·9	3·7	75
	34·60	10·6	26·55	0·66	5·1	4·3	125

* Unreliable results

1964	‰	°C	g/L	mg/m^3	$\frac{D430}{D665}$	µg at/L	m
16·viii	34·72			0·41	7·2	9·2	200
29·viii	34·07	9·1	26·40	1·72	4·7	2·0	0
	34·36	9·2	26·40	1·21	4·8	3·3	75
	34·40	9·2	26·63	1·21	4·8	3·4	125
	34·47			0·93	5·0	6·0	200
13·ix	34·07	9·9	26·27	3·18	3·5	0·6	0
	34·25	9·8	26·42	4·45	3·8	2·2	10
	34·38	9·8	26·53	2·11	4·0	3·5	25
	34·54	9·8	26·65	0·97	4·2	6·2	50
	34·63	10·0	26·69	0·47	6·1	6·6	75
	34·63	10·0	26·69	0·66	5·9	7·1	125
	34·63			0·29	9·2	10·0	200
26·ix	34·29	11·1	26·22	1·88	4·6	0·3	0
	34·54	11·1	26·42	3·98	3·5	0·3	10
	34·56	10·9	26·47	3·62	3·9	0·5	25
	34·87	11·7	26·56	1·49	3·8	6·6	50
	34·76	10·9	26·61	0·99	4·5	8·7	75
	34·67	10·9	26·56	0·40	5·8	9·3	125
	34·65			0·37	7·9	9·9	200
11·x	34·23	10·9	26·22	2·66	4·2	0·3	0
	34·25	10·7	26·26	3·06	4·2	0·5	10
	34·34	10·6	26·36	2·44	4·3	0·6	25
	34·34	10·5	26·38	1·89	4·4	0·8	50
	34·38	10·4	26·42	2·08	4·3	0·8	75
	34·63	9·8	26·72	0·47	3·7	8·1	125
	34·65			0·29	5·0	10·2	200
29·x	34·25	13·0	25·83	1·17	4·7	0·5	0
	34·47	11·9	26·22	1·51	4·1	0·9	10
	34·51	11·6	26·30	0·77	6·2	0·5	25
	34·61	11·1	26·48	0·45	8·2	2·4	50
	34·65	11·1	26·50	0·71	6·1	2·4	75
	34·67	10·6	26·61	0·36	5·8	6·0	125
	34·69			0·22	7·4	9·2	200
17·xi	34·52	13·0	26·04	1·13	5·3	0·1	0

	‰	°C	g/L	mg/m^3	$\frac{D430}{D665}$	µg at/L	m
1964 17·xi	34·52	12·9	26·06	1·69	4·1	0·1	10
	34·58	12·7	26·15	1·71	4·2	0·1	25
	34·72	11·4	26·50	0·52	5·6	2·8	50
	34·63	11·1	26·49	0·24	8·9	3·8	75
	34·69	10·6	26·62	0·26	6·2	6·9	125
	34·69			0·23	5·6	8·9	200
5·xii	34·56	13·9	25·88	1·32	5·0	0·5	0
	34·61	12·8	26·16	0·95	4·2	0·2	10
	34·67	12·2	26·31	1·53	4·3	0·6	25
	34·69	11·5	26·46	0·62	4·5	1·7	50
	34·69	10·8	26·58	0·36	3·9	5·8	75
	34·67	10·5	26·63	0·19	5·7	8·8	125
	34·70			0·27	5·0	9·7	200
21·xii	34·51	15·6	25·48	1·06	6·3	0·2	0
	34·56	11·7	26·32	0·84	5·5	3·1	10
	34·58	11·5	26·38	0·52	6·5	3·8	25
	34·60	10·9	26·50	0·24	8·0	5·0	50
	34·67	10·8	26·57	0·17	9·0	7·4	75
	34·67	10·7	26·59	0·33	3·7	7·5	125
	34·69			0·52	2·7	7·3	200
1965 7·i	34·54	17·9	24·97	0·29	7·2	0·1	0
	34·54	16·0	25·42	0·91	4·5	0·1	10
	34·58	15·0	25·67	0·66	4·7	1·1	25
	34·67	12·4	26·27	0·69	4·7	5·0	50
	34·69	12·0	26·36	0·43	5·0	5·1	75
	34·67	11·1	26·52	0·13	7·5	11·1	125
	34·67			0·13	7·0	12·9	200
24·i	34·63	16·0	25·48	0·94	4·9	1·1	0
	34·61	15·7	25·54	0·98	5·0	1·3	10
	34·63	13·9	25·94	1·15	4·6	2·5	25
	34·63	12·8	26·17	0·77	4·9	5·9	50
	34·69	11·1	26·53	0·32	6·4	11·4	75
	34·69	10·8	26·58	0·25	6·0	12·7	125

1965	°/oo	°C	g/L	mg/m^3	$\frac{D430}{D665}$	µg at/L	m
24·i	34·70			0·26	5·3	12·2	200
24·ii	34·34	16·4	25·17	1·32	8·3	0·8	0
	34·40	15·3	25·46	1·85	6·7	1·2	10
	34·49	14·6	25·68	1·14	4·1	2·5	25
	34·58	13·7	25·94	0·49	5·8	2·9	50
	34·63	12·6	26·21	0·19	9·4	9·6	75
	34·69	11·7	26·42	0·27	6·0	13·0	125
	34·65			0·17	6·4	13·3	200
12·iii	34·11	15·9	25·11	1·82	4·4	1·1	0
	34·16	15·7	25·19	1·17	4·4	2·5	10
	34·33	14·8	25·56	0·91	4·6	4·0	25
	34·43	14·3	25·70	0·51	5·0	5·4	50
	34·45	13·9	25·80	0·26	6·8	5·9	75
	34·49	12·9	26·03	0·27	5·3	10·5	125
	34·65			0·18	5·8	15·3	200
4·iv	34·40	14·4	25·66	0·78	4·6	0·2	0
	34·42	14·3	25·68	0·70	5·3	0·2	10
	34·43	13·9	25·79	1·62	4·3	0·2	25
	34·45	12·6	26·06	0·63	5·1	11·7	50
	34·47	12·2	26·16	0·35	6·5	11·7	75
	34·52	11·3	26·37	0·26	5·0	13·5	125
	34·52			0·15	5·0	15·6	200
18·iv	33·26	14·8	24·65	0·55	4·4	1·3	0
	34·27	14·4	25·54	0·58	5·0	3·8	10
	34·34	13·9	25·70	1·39	4·0	2·3	25
	34·43	12·8	26·01	0·65	5·0	9·3	50
	34·47	12·1	26·18	0·18	6·4	11·8	75
	34·49	11·7	26·26	0·21	4·7	13·5	125
	34·52			0·17	6·0	13·8	200
5·v	34·02	13·1	25·64	0·50	5·7	2·8	0
	34·09	13·1	25·68	0·58	7·1	3·1	10
	34·11	13·0	25·72	0·55	5·9	6·6	25
	34·42	12·8	25·99	0·36	5·2	9·3	50
	34·42	12·7	26·01	0·35	6·7	8·0	75
	34·42	12·5	26·05	0·38	6·0	9·0	125
	34·49			0·35	6·2	10·4	200

SURFACE RADIATION, SECCHI DISC READINGS AND "GROSS" PRIMARY PRODUCTION

	Surface Radiation g $Cal/cm^2/day$	"Gross" Production g $C/m^2/day$	Secchi Disc Readings m
1964			
14·iv	209	0·25	-
30·iv	231	0·10	-
16·v	183	0·15	-
1·vi	174	0·22	-
15·vi	156	0·10	-
26·vi	070	0·09	-
12·vii	049	0·10	-
2·viii	129	0·24	-
16·viii	277	0·28	6·0
29·viii	320	0·48	6·7
13·ix	247	0·89	5·3
26·ix	355	0·80	6·3
11·x	454	1·05	5·5
29·x	625	0·55	4·3
17·xi	667	0·75	7·0
5·xii	606	0·65	9·0
21·xii	561	0·39	6·0
1965			
7·i	345	0·35	12·0
24·i	458	0·49	9·0
24·ii	221	0·38	5·5
12·iii	209	0·31	4·0
4·iv	230	0·61	13·5
18·iv	230	0·09	5·5
5·v	220	0·09	3·0

APPENDIX IV

WEIGHTS OF ZOOPLANKTON CAPTURED IN QUANTITATIVE OBLIQUE HAULS FROM 200m

	Plankton	Wet Wt. mg/m3	Dry Wt. mg/m3	% Organic Matter / Dry Weight
1964				
14·iv	General Pl.	55·4	6·68	96·7
	Euphausids	15·9	1·27	64·2
30·iv	General Pl.	132·4	9·98	68·5
	Salps	94·2	9·37	72·3
16·v	General Pl.	20·6	2·96	75·4
	Euphausids	14·5	0·43	32·2
	Salps	17·9	0·95	33·3
1·vi	General Pl.	52·1	7·85	72·4
	Euphausids	26·1	4·36	87·5
15·vi	General Pl.	11·9	1·52	56·1
	Euphausids	19·9	2·36	74·8
26·vi	General Pl.	10·9		
12·vii	General Pl.	102·2	7·94	75·8
	Euphausids	26·1	3·68	85·2
2·viii	General Pl.	10·3	1·44	84·2
16·viii	General Pl.	41·3	5·13	82·6
	Euphausids	11·7	1·97	89·5
29·viii	General Pl.	81·5	10·74	83·4
	Euphausids	3·5		
13·ix	General Pl.	64·7	8·65	82·8
26·ix	General Pl.	56·8	9·60	86·2
	Euphausids	5·2		
11·x	General Pl.	162·5	15·00	83·5
29·x	General Pl.	167·5	21·98	86·9
17·xi	General Pl.	31·2	4·60	86·2
	Euphausids	17·9	2·44	87·4
5·xii	General Pl.	104·4	14·01	91·6
	Euphausids	9·1	1·06	88·7
21·xii	General Pl.	392·0	67·50	95·8
	Euphausids	11·1	1·30	93·2
1965				
7·i	General Pl.	30·7	5·40	90·0
	Euphausids	10·6	1·68	85·0
24·i	General Pl.	13·4	2·75	63·0
	Euphausids	5·7	0·62	64·8
	Salps	567·0	28·20	85·4
24·ii	General Pl.	50·0	8·38	84·5
	Euphausids	4·6	0·34	57·9
12·iii	General Pl.	52·6	6·33	79·7
	Euphausids	6·9	0·81	76·1
4·iv	General Pl.	74·8	11·09	85·0
	Euphausids	51·5	3·98	80·7
18·iv	General Pl.	69·5	8·54	82·7
	Salps	38·7	1·78	68·4
5·v	General Pl.	44·4	7·31	82·4
	Euphausids	18·2	3·04	83·9